Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49"Degree Nozzle, Mid-Plane Azimuth, 1.544 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** *.*
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.544$ Location of Blind Zone above nozzle bottom (inch)

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 4.034$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.25$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\nu := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^{5}$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

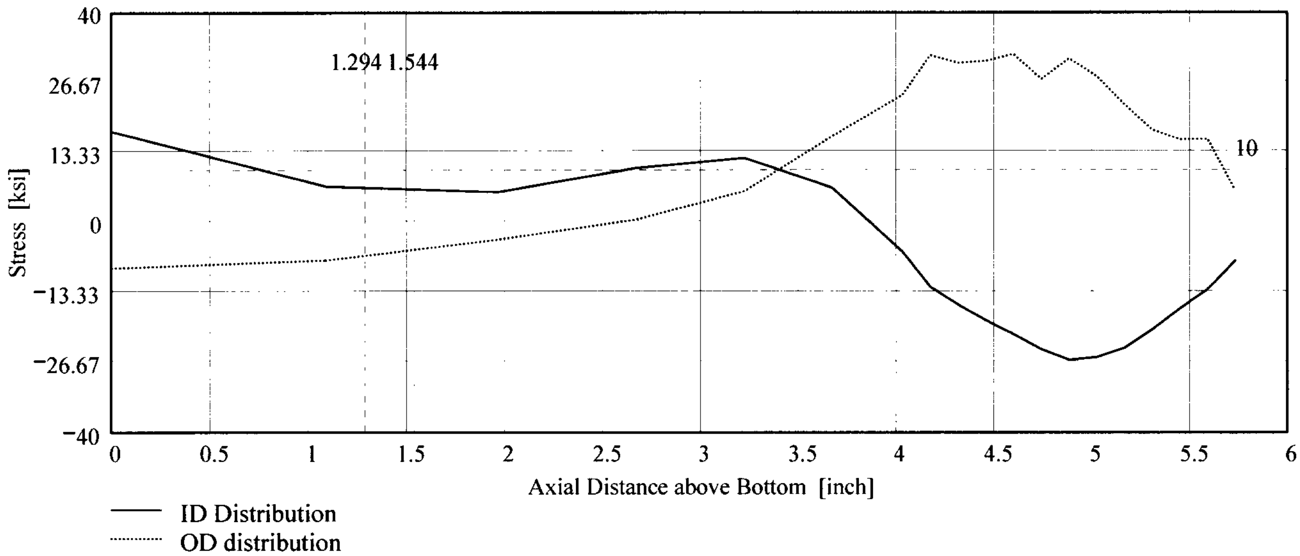
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	17.35	8.19	2.28	-3.06	-8.64
1	1.09	6.89	1.47	-2.22	-5.44	-7.2
2	1.96	5.78	2.36	0.75	-0.95	-3.23
3	2.66	10.29	7.15	5.32	3.43	0.49
4	3.23	12.24	7.03	6.83	7.24	5.95
5	3.67	6.58	4.66	5.87	12.45	16.38
6	4.03	-5.62	-1.3	4.18	17.86	24.28
7	4.18	-12.25	-6.01	2.74	20.52	31.88
8	4.32	-15.64	-9.13	2.2	21.5	30.45
9	4.46	-18.61	-11.79	1.32	20.22	30.79
10	4.6	-21.26	-13.55	0.57	19.39	32.09

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $AllID := Data_{All}^{\langle 1 \rangle}$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & 17.354 & 8.186 & 2.284 & -3.064 & -8.637 \\ 1.091 & 6.892 & 1.47 & -2.224 & -5.444 & -7.199 \\ 1.964 & 5.781 & 2.359 & 0.754 & -0.955 & -3.232 \\ 2.664 & 10.289 & 7.148 & 5.324 & 3.428 & 0.494 \\ 3.225 & 12.243 & 7.028 & 6.829 & 7.244 & 5.952 \\ 3.674 & 6.579 & 4.659 & 5.865 & 12.453 & 16.377 \\ 4.034 & -5.621 & -1.296 & 4.184 & 17.859 & 24.278 \\ 4.176 & -12.251 & -6.006 & 2.741 & 20.517 & 31.88 \\ 4.317 & -15.641 & -9.131 & 2.2 & 21.496 & 30.446 \\ 4.459 & -18.614 & -11.785 & 1.319 & 20.216 & 30.786 \\ 4.601 & -21.257 & -13.548 & 0.574 & 19.393 & 32.088 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := \text{regress}(Axl, ID, 3)$ $\quad R_{OD} := \text{regress}(Axl, OD, 3)$

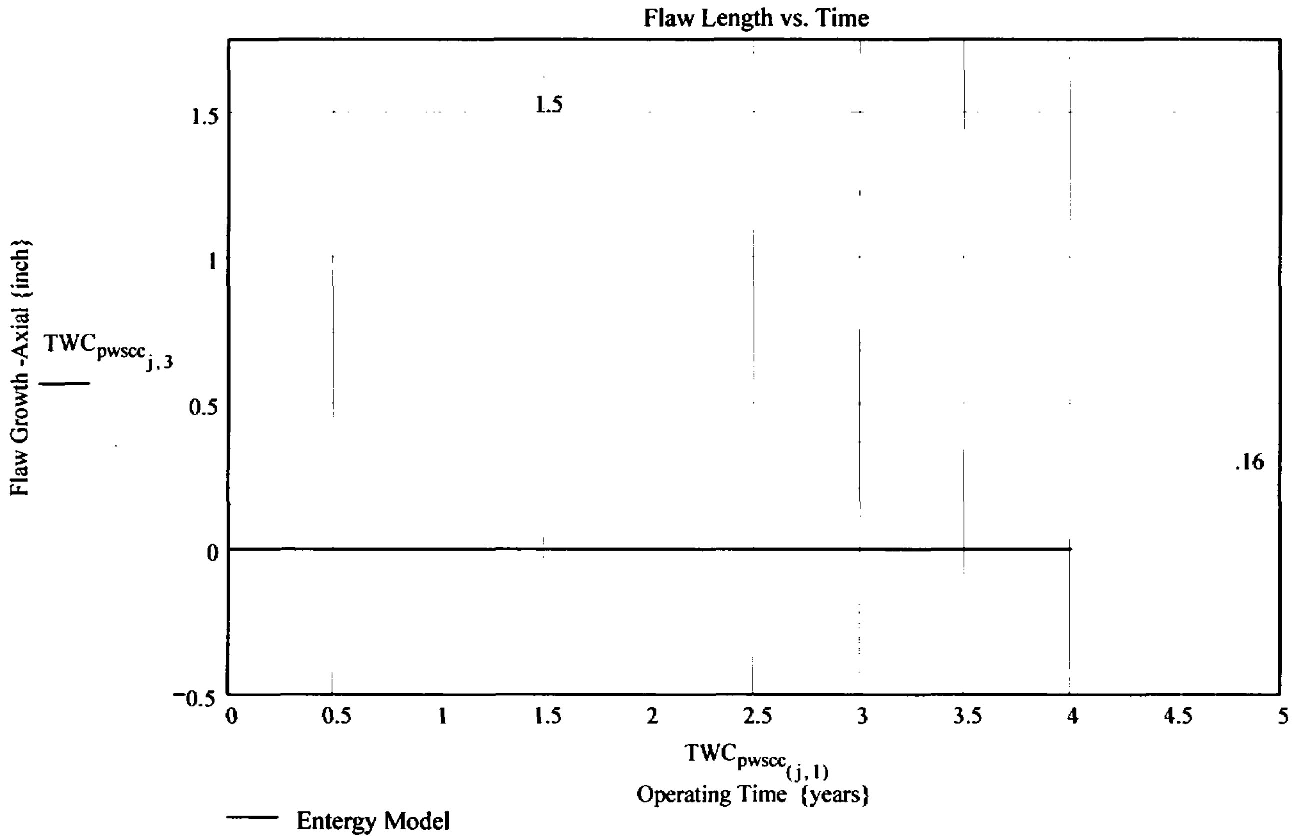
$FL_{Cntr} := BZ - l$ Flaw Center above Nozzle Bottom

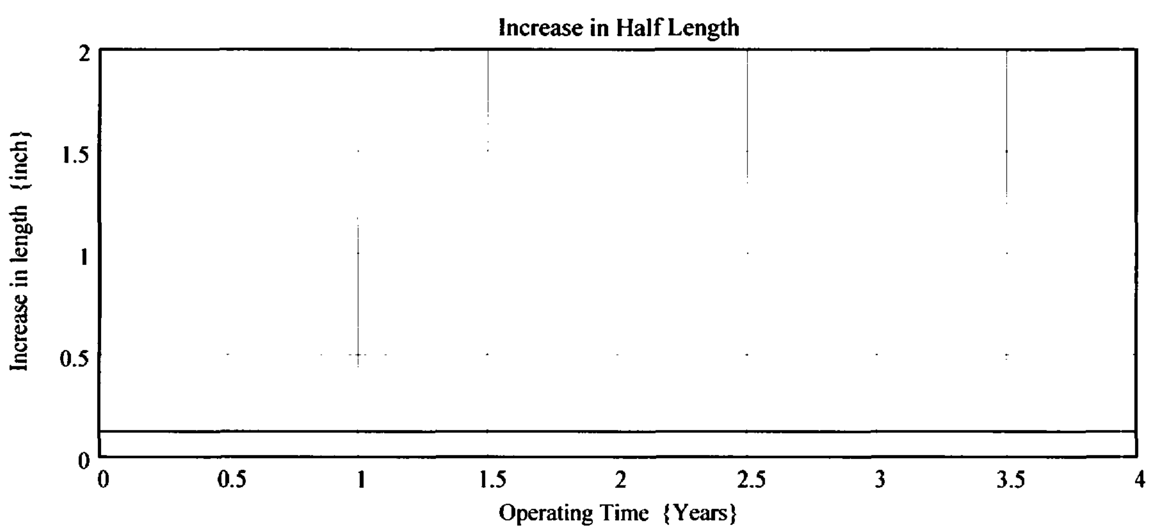
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

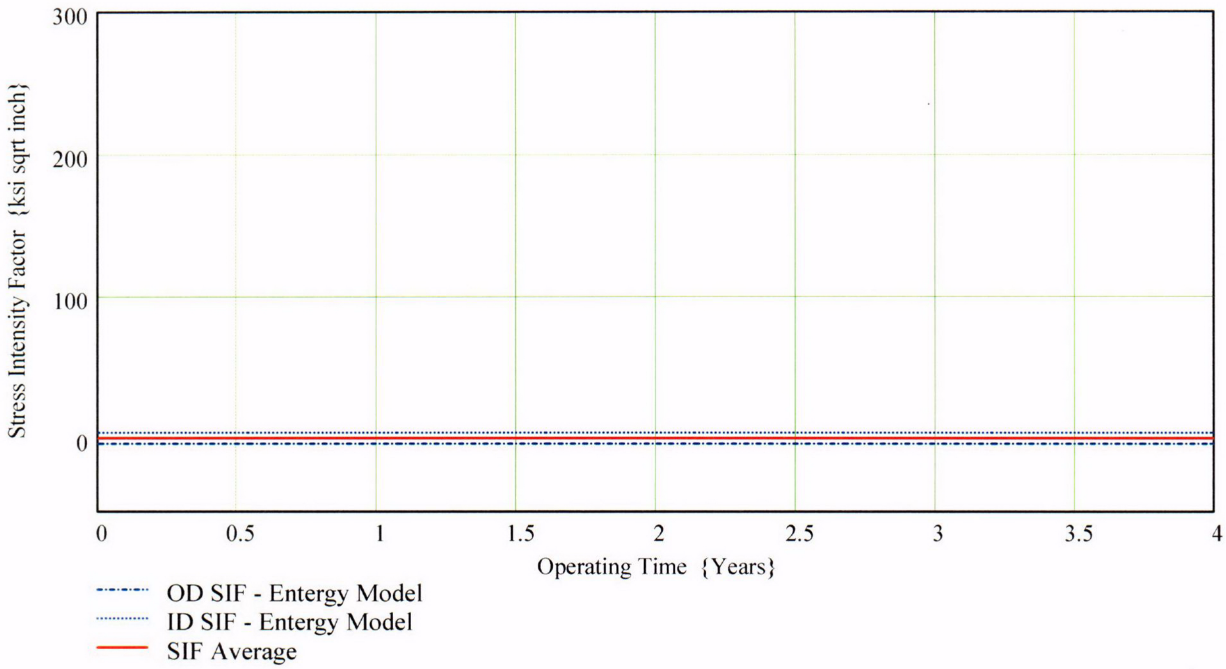
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

$Prop_{Length} = 2.49$

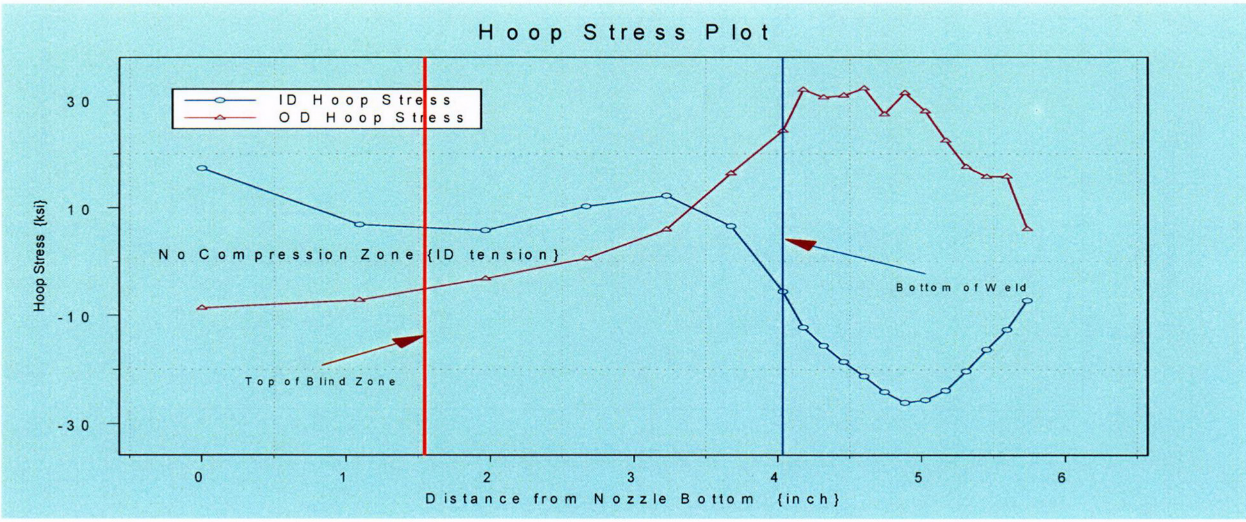


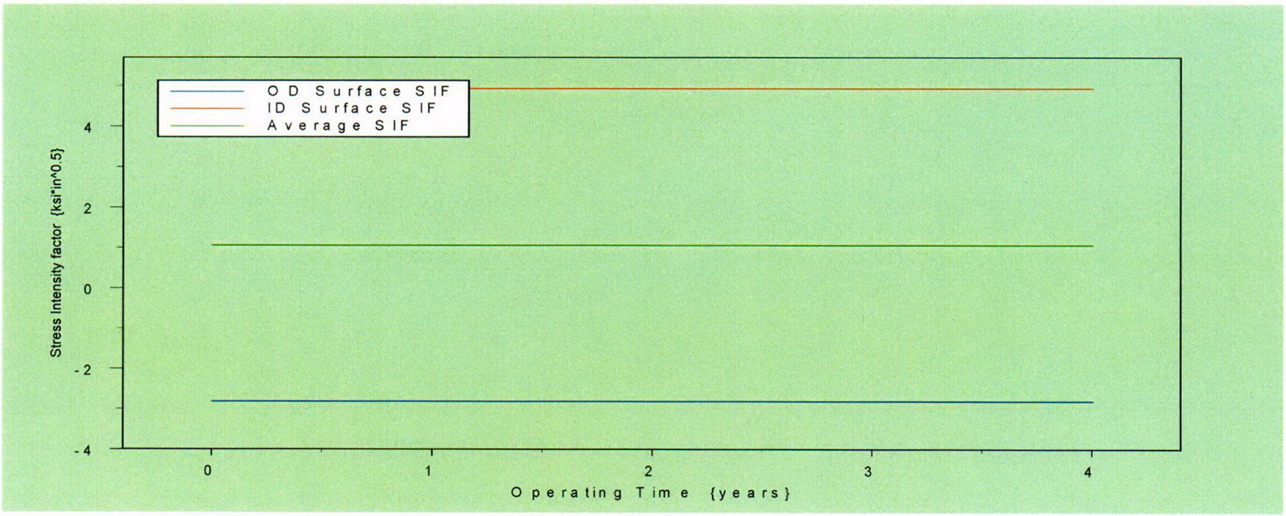


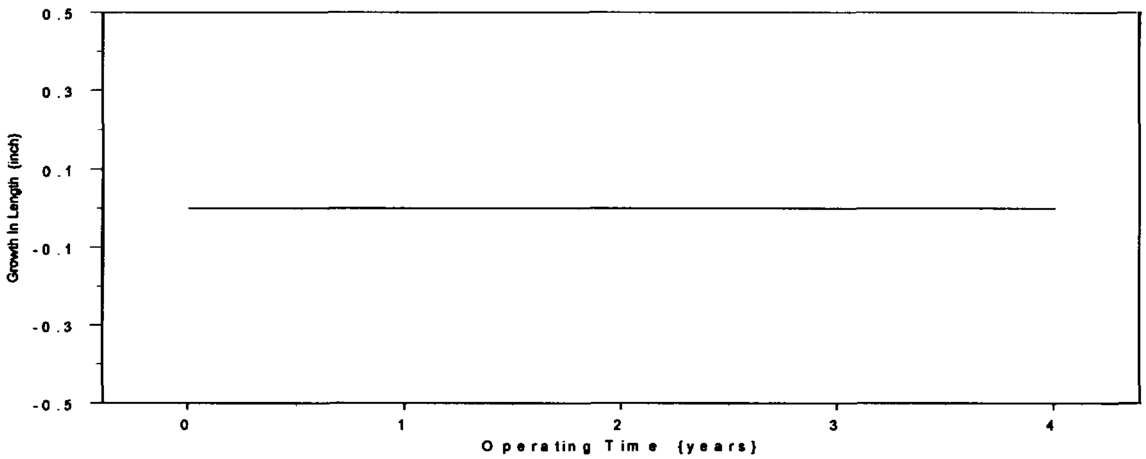

300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$ | $TWC_{pwscc_{(j,7)}} =$ | $TWC_{pwscc_{(j,8)}} =$

$TWC_{pwscc_{(j,6)}}$	$TWC_{pwscc_{(j,7)}}$	$TWC_{pwscc_{(j,8)}}$
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141
-2.817	4.929	1.141


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
30
10
-10
-30
Hoop Stress {ksi}
No Compression Zone {ID tension}
Top of Blind Zone
Bottom of Weld
0
1
2
3
4
5
6
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
4
2
0
-2
-4
Stress Intensity factor {ksi*in^0.5}
0
1
2
3
4
Operating Time {years}


0.5
0.3
0.1
-0.1
-0.3
-0.5
Growth In Length (inch)
0
1
2
3
4
Operating Time (years)

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :
1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49" Degree Nozzle, Downhill Azimuth, Augmented Analysis 1.043" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessar to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represnets the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.043$ *This allows a 0.25 inch freespan below bottom of weld*

To place the flaw with repsect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "c- tip" located at the reference point (Enter 1)

2) The Center of the flaw at the reference point (Enter 2)

3) The lower "c- tip" located at the reference point (Enter 3).

$Val := 2$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.293$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.661 \cdot 0.12$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$R_o := \frac{od}{2} \qquad R_{id} := \frac{id}{2} \qquad t := R_o - R_{id} \qquad R_m := R_{id} + \frac{t}{2} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$CF_{inhr} := 1.417 \cdot 10^5 \qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right| \qquad c_0 := \frac{L}{2} \qquad R_t := \frac{R_m}{t}$$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$$C_0 := C_{01}$$ 75 th percentile MRP-55 Revision 1

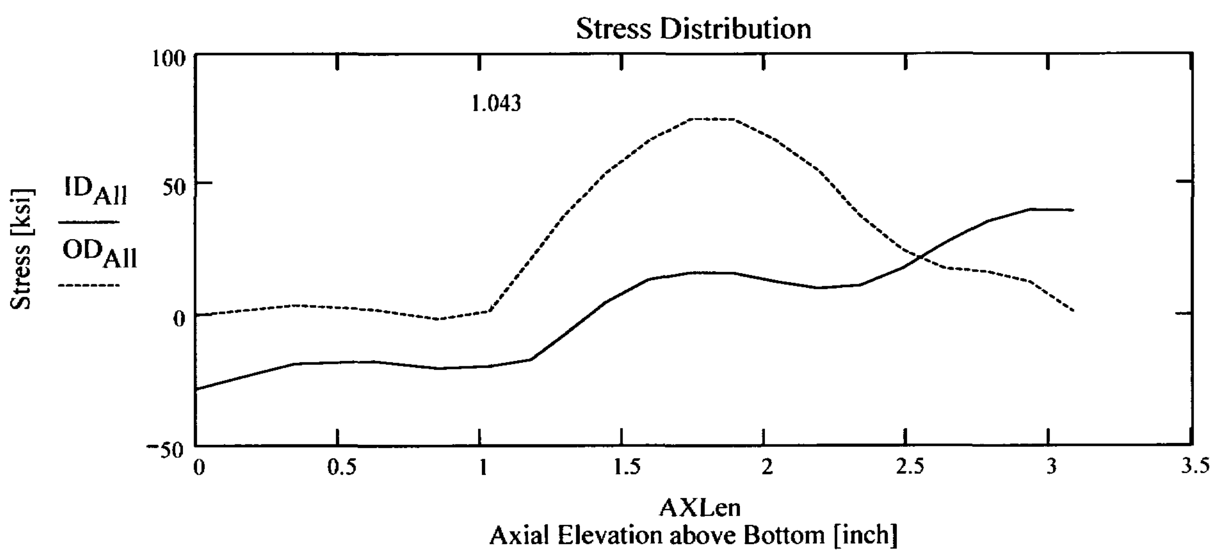
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum to maximum recorded on data sheet(inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-28.32	-18.3	-12.16	-6.2	-0.02
1	0.35	-18.79	-12.49	-6.61	-1.37	3.65
2	0.63	-17.84	-10.52	-4.41	-0.48	2.08
3	0.85	-20.52	-12.97	-5.9	-0.87	-1.54
4	1.03	-19.66	-11.83	-5.29	0.23	1.46
5	1.18	-17.2	-10.59	-0.52	16.33	21.02
6	1.29	-8.02	-2.2	10.46	32.66	37.29
7	1.44	4.78	9.56	24.9	38.18	54.09
8	1.59	13.25	18.57	35.28	52.81	66.52
9	1.74	16	22.02	39.19	62.95	75

$AXLen := AllData^{\langle 0 \rangle}$ $\qquad ID_{All} := AllData^{\langle 1 \rangle}$ $\qquad OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -28.324 & -18.299 & -12.16 & -6.201 & -0.021 \\ 0.35 & -18.794 & -12.495 & -6.607 & -1.366 & 3.655 \\ 0.63 & -17.838 & -10.518 & -4.407 & -0.477 & 2.08 \\ 0.854 & -20.517 & -12.968 & -5.902 & -0.874 & -1.536 \\ 1.034 & -19.663 & -11.831 & -5.288 & 0.227 & 1.46 \\ 1.178 & -17.203 & -10.587 & -0.515 & 16.326 & 21.019 \\ 1.293 & -8.023 & -2.205 & 10.461 & 32.658 & 37.289 \\ 1.442 & 4.778 & 9.557 & 24.903 & 38.177 & 54.089 \\ 1.591 & 13.252 & 18.569 & 35.278 & 52.808 & 66.517 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad MD := Data^{\langle 3 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad TQ := Data^{\langle 4 \rangle}$ $\quad QT := Data^{\langle 2 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $\quad R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{vmatrix} Ref_{Point} - c_0 \ \text{if } Val = 1 \\ Ref_{Point} \ \text{if } Val = 2 \\ Ref_{Point} + c_0 \ \text{otherwise} \end{vmatrix}$$

Flaw center Location Location above Nozzle Bottom

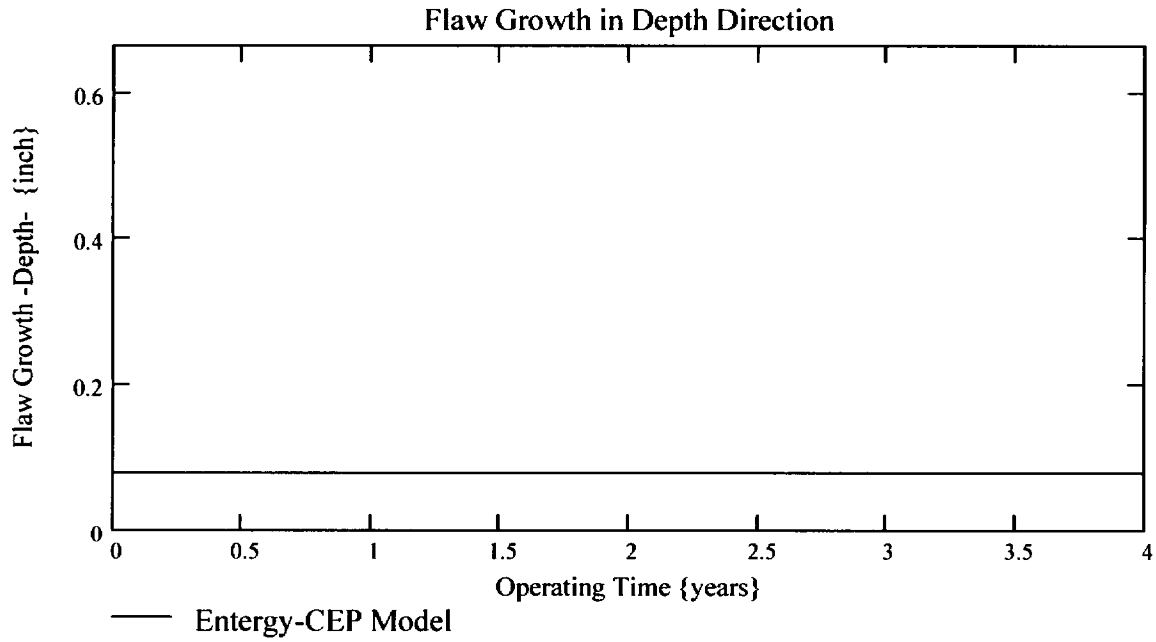
$U_{Tip} := FL_{Cntr} + c_0$

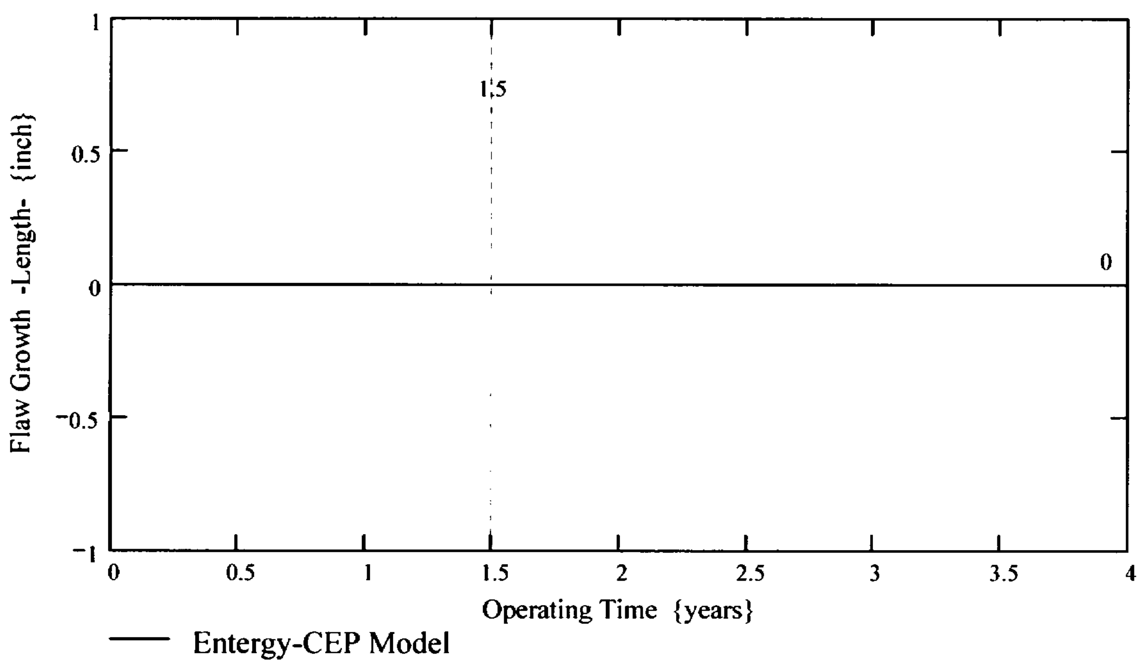
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

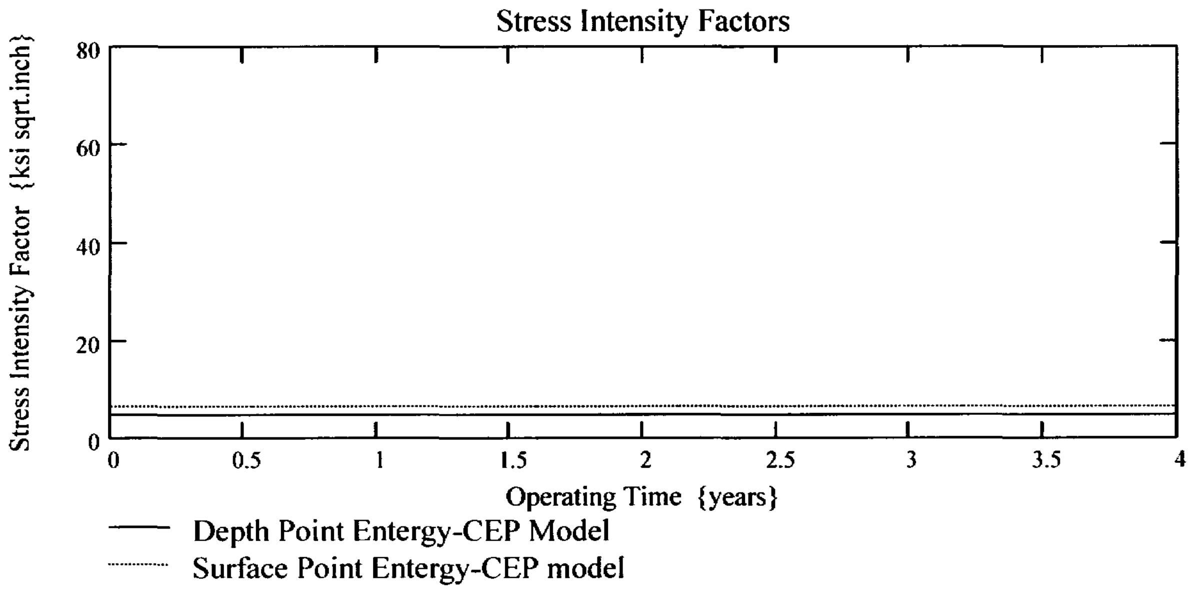
No User Input is required beyond this Point

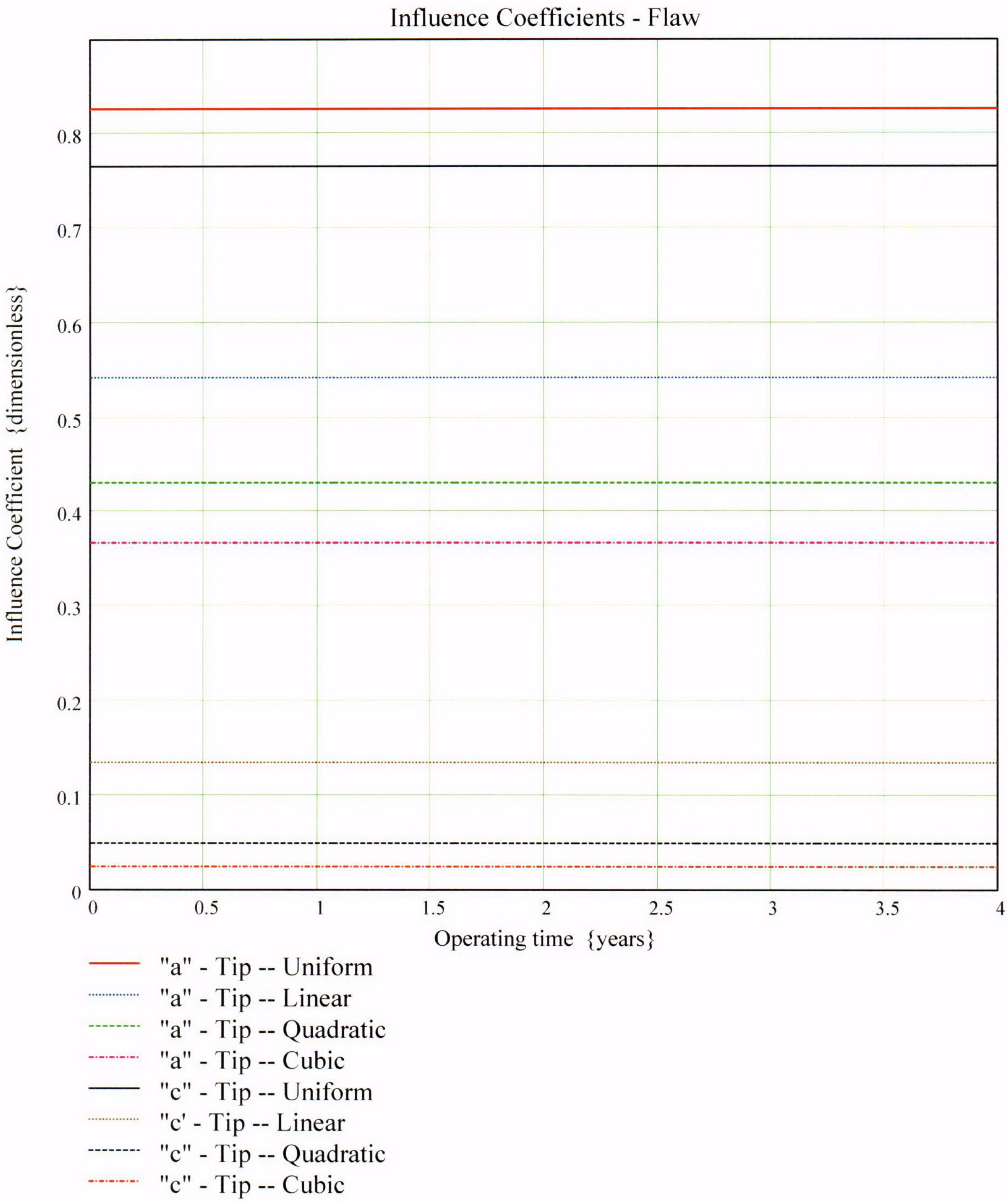
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.09$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

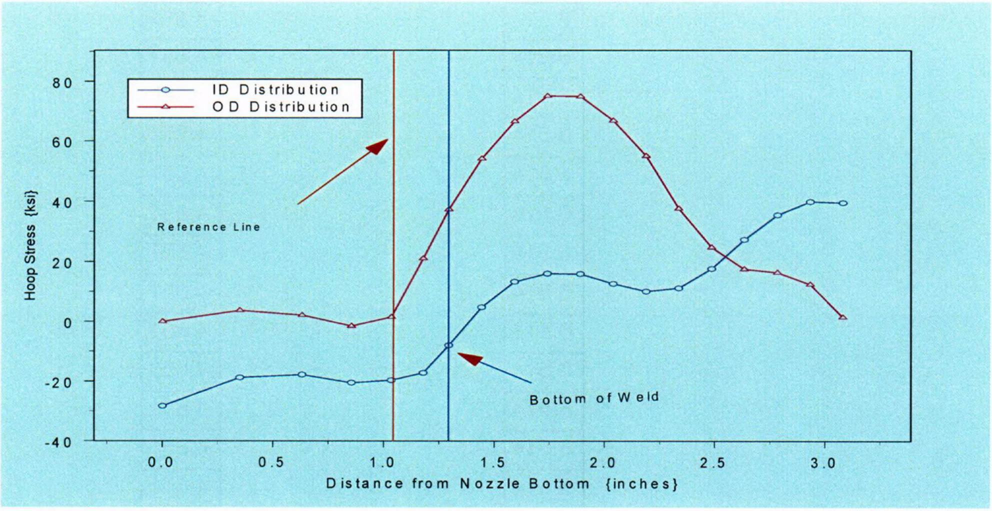
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

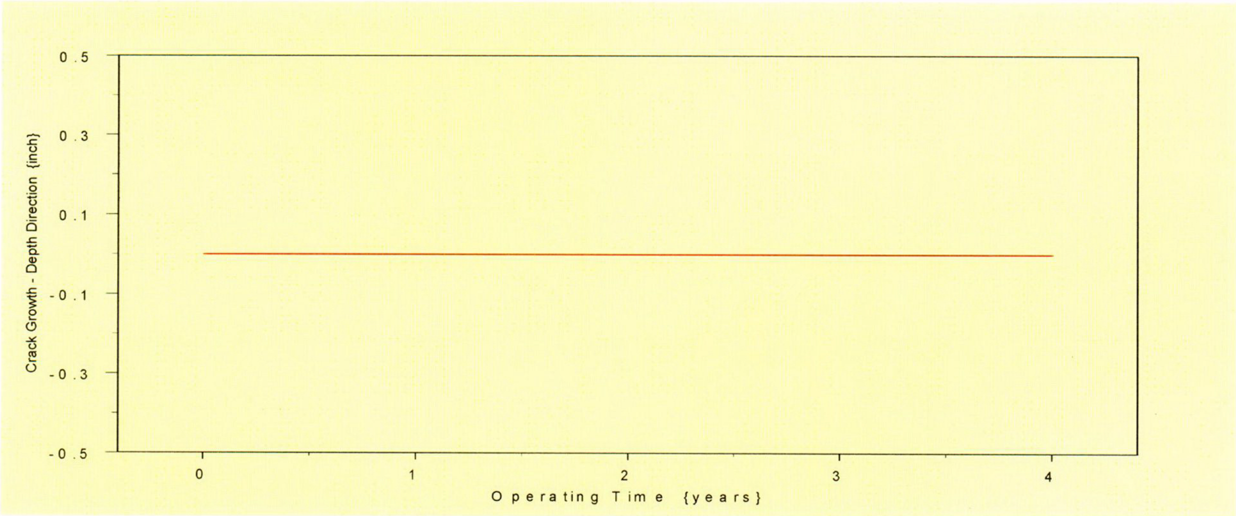
$CGR_{sambi_{(k,6)}} =$

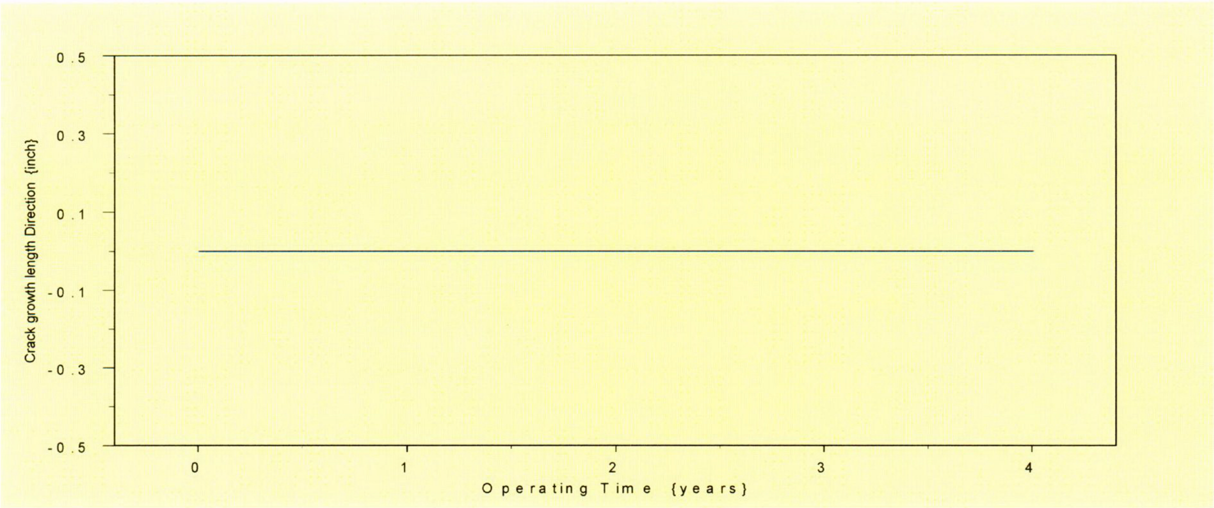
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514
6.514

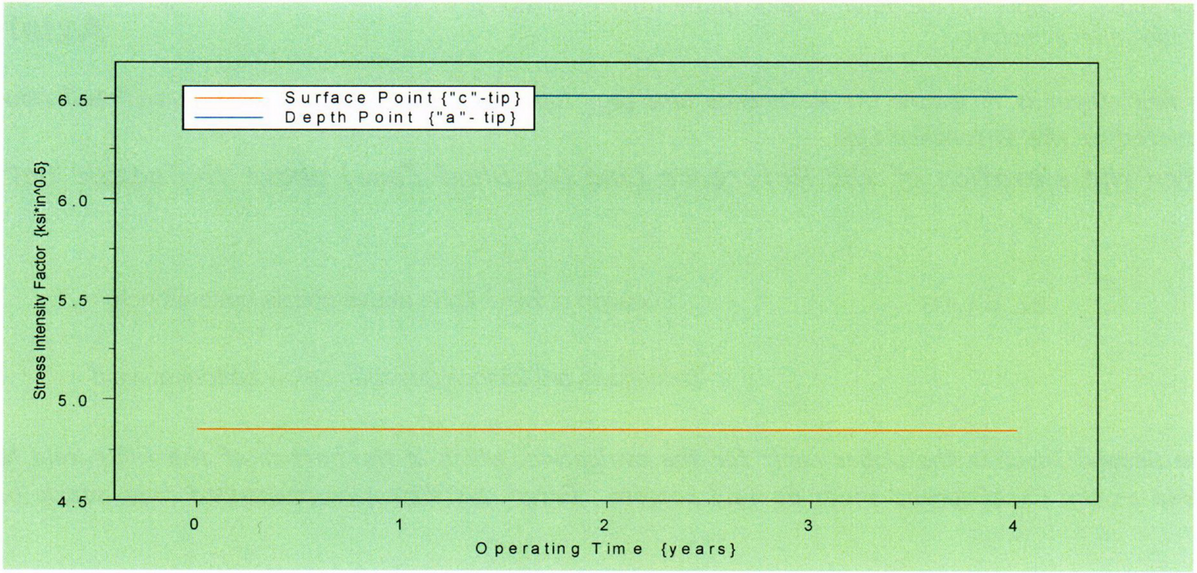
$CGR_{sambi_{(k,5)}} =$

4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851
4.851


ID Distribution
OD Distribution
Reference Line
Bottom of Weld
Hoop Stress (ksi)
80
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom {inches}


Crack Growth - Depth Direction (inch)
0.5
0.3
0.1
-0.1
-0.3
-0.5
0
1
2
3
4
Operating Time {years}


Crack growth length Direction {inch}
0.5
0.3
0.1
-0.1
-0.3
-0.5
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
6.5
6.0
5.5
5.0
4.5
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49"Degree Nozzle, Downhill Azimuth, Augmented Analysis
1.043 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** .
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.043$ Location of Blind Zone above nozzle bottom (inch)

This allows a 0.25 inch freespan below bottom of weld

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 1.293$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.25$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$v := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^{5}$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

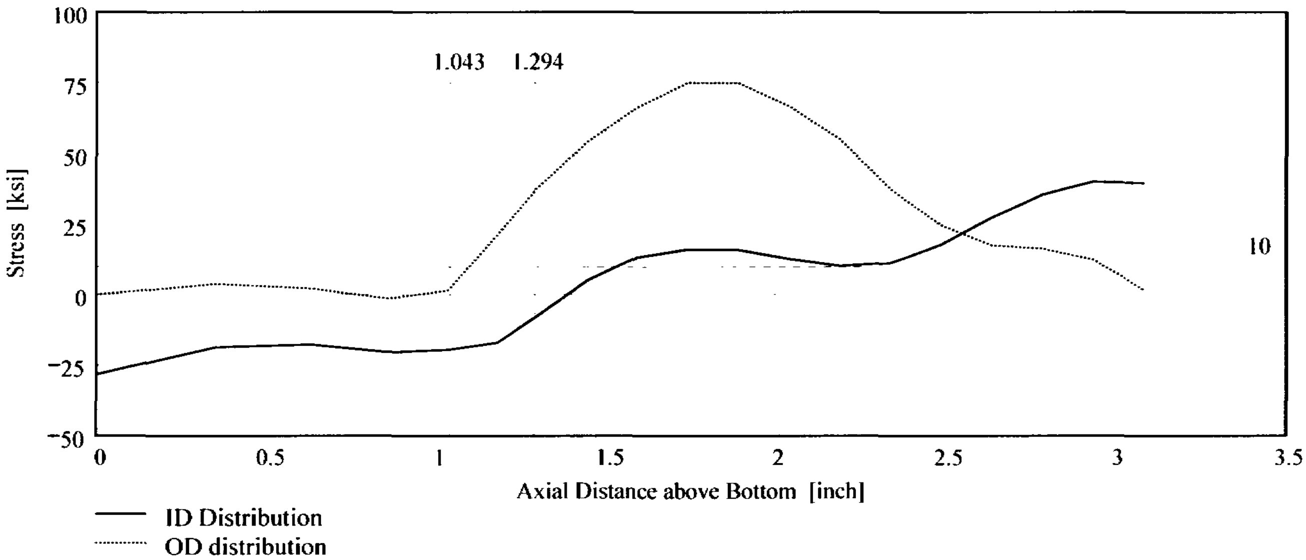
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All}$:=

	0	1	2	3	4	5
0	0	-28.32	-18.3	-12.16	-6.2	-0.02
1	0.35	-18.79	-12.49	-6.61	-1.37	3.65
2	0.63	-17.84	-10.52	-4.41	-0.48	2.08
3	0.85	-20.52	-12.97	-5.9	-0.87	-1.54
4	1.03	-19.66	-11.83	-5.29	0.23	1.46
5	1.18	-17.2	-10.59	-0.52	16.33	21.02
6	1.29	-8.02	-2.2	10.46	32.66	37.29
7	1.44	4.78	9.56	24.9	38.18	54.09
8	1.59	13.25	18.57	35.28	52.81	66.52
9	1.74	16	22.02	39.19	62.95	75

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $AllID := Data_{All}^{\langle 1 \rangle}$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled Data$_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\text{Data} := \begin{pmatrix} 0 & -28.324 & -18.299 & -12.16 & -6.201 & -0.021 \\ 0.35 & -18.794 & -12.495 & -6.607 & -1.366 & 3.655 \\ 0.63 & -17.838 & -10.518 & -4.407 & -0.477 & 2.08 \\ 0.854 & -20.517 & -12.968 & -5.902 & -0.874 & -1.536 \\ 1.034 & -19.663 & -11.831 & -5.288 & 0.227 & 1.46 \\ 1.178 & -17.203 & -10.587 & -0.515 & 16.326 & 21.019 \\ 1.293 & -8.023 & -2.205 & 10.461 & 32.658 & 37.289 \\ 1.442 & 4.778 & 9.557 & 24.903 & 38.177 & 54.089 \\ 1.591 & 13.252 & 18.569 & 35.278 & 52.808 & 66.517 \end{pmatrix}$$

$\text{Axl} := \text{Data}^{\langle 0 \rangle}$ $\text{ID} := \text{Data}^{\langle 1 \rangle}$ $\text{OD} := \text{Data}^{\langle 5 \rangle}$

$R_{ID} := \text{regress}(\text{Axl}, \text{ID}, 3)$ $R_{OD} := \text{regress}(\text{Axl}, \text{OD}, 3)$

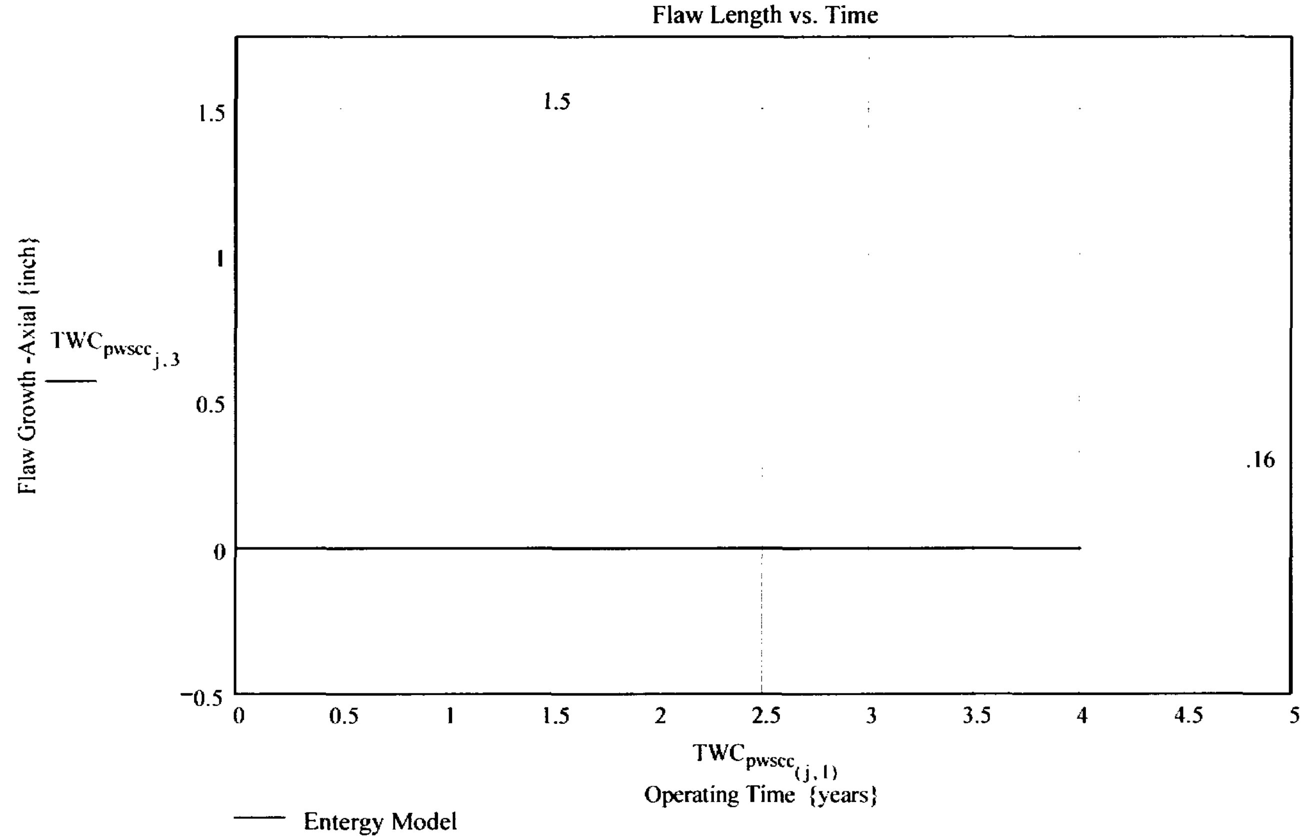
$FL_{Cntr} := BZ - l$ Flaw Center above Nozzle Bottom

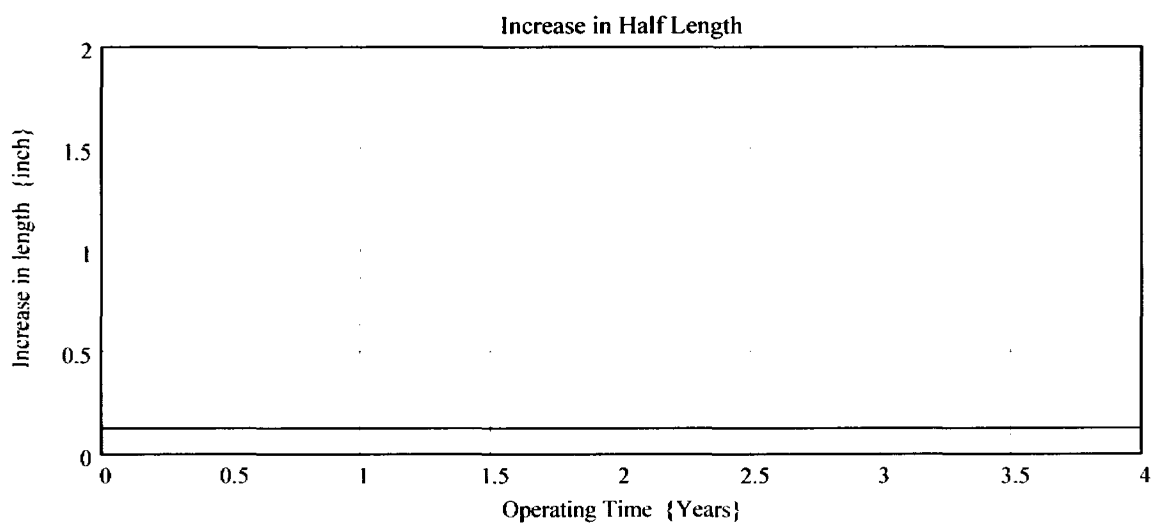
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

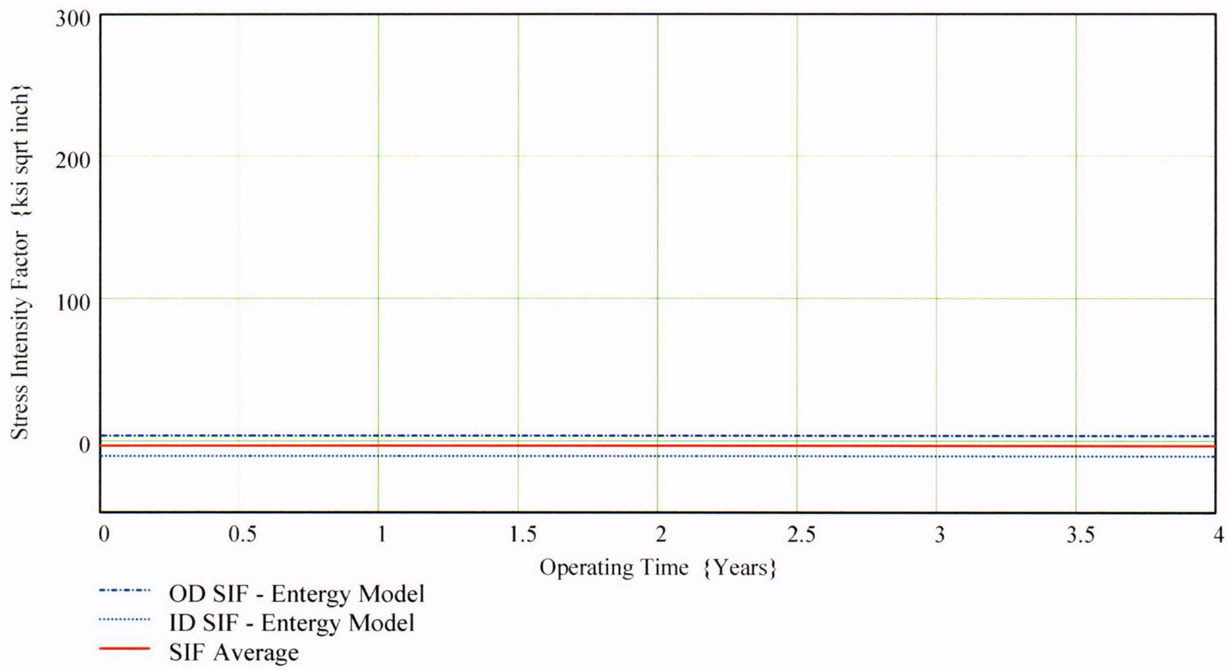
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

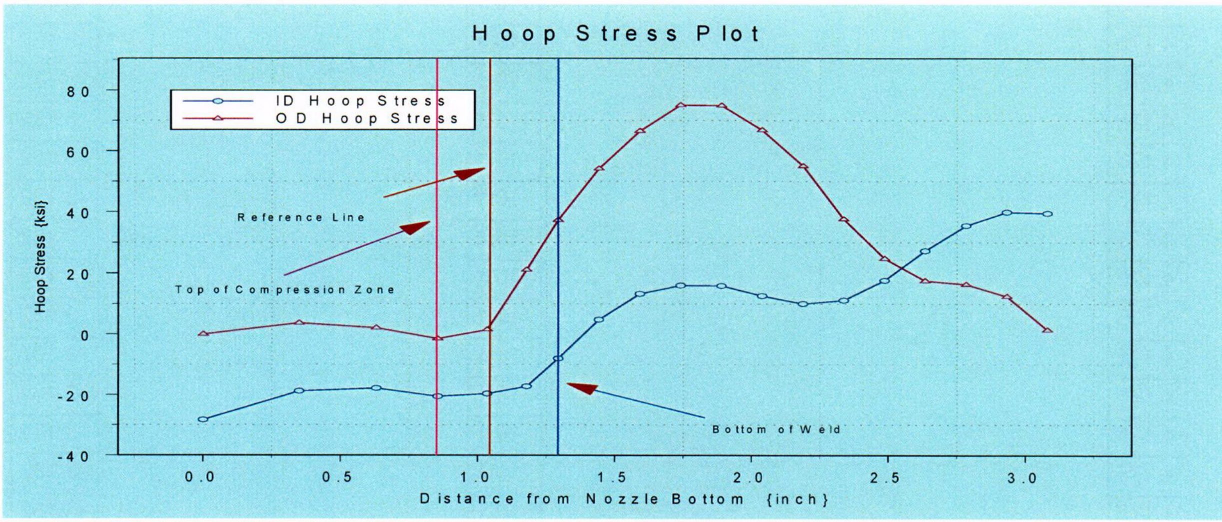
$Prop_{Length} = 0.25$

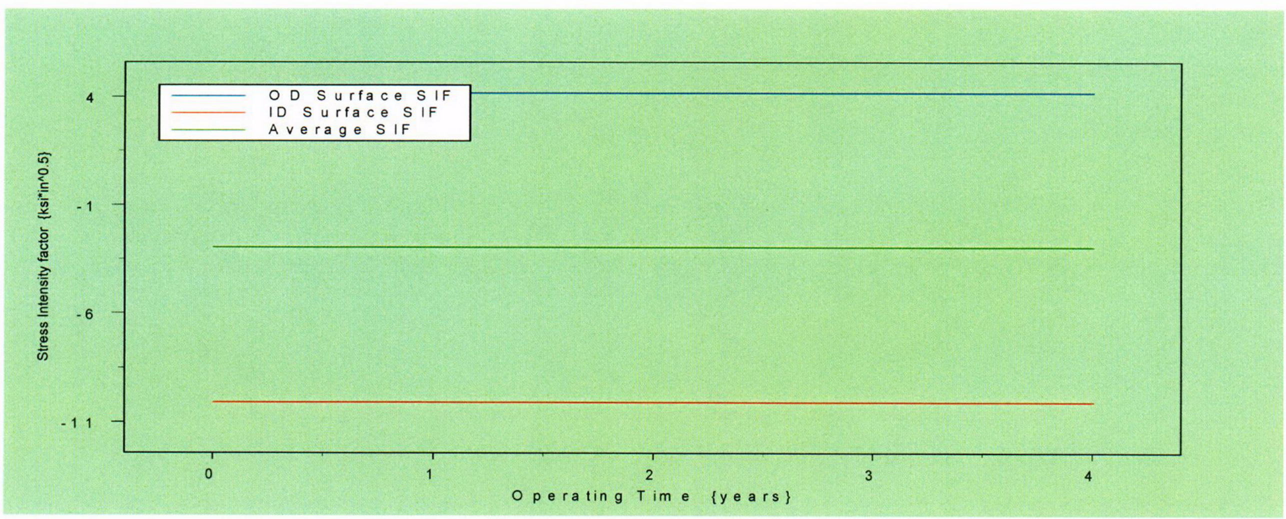


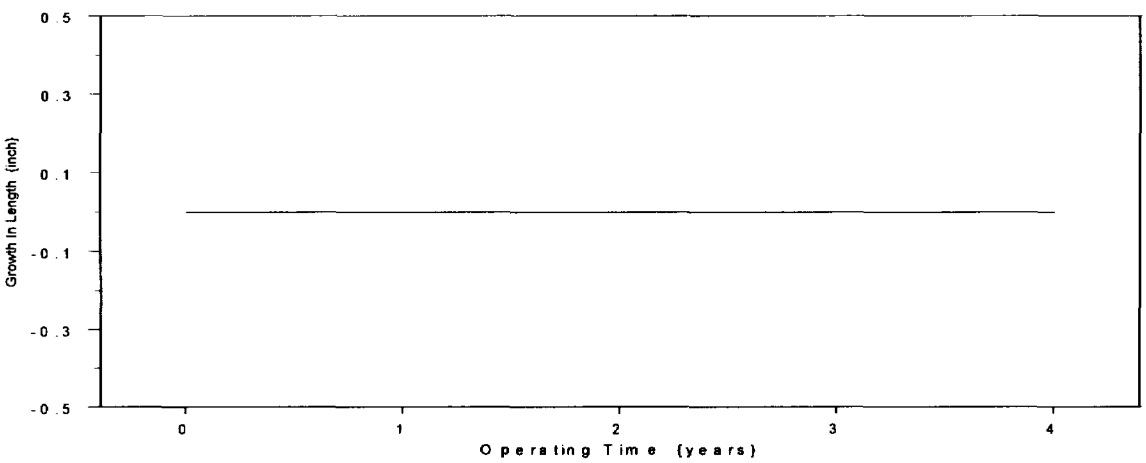



300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$	$TWC_{pwscc_{(j,7)}} =$	$TWC_{pwscc_{(j,8)}} =$
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132
4.175	-10.1	-3.132


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Reference Line
Top of Compression Zone
Bottom of Weld
Hoop Stress {ksi}
80
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
4
-1
-6
-11
0
1
2
3
4
Operating Time {years}


0.5
0.3
0.1
-0.1
-0.3
-0.5
Growth in Length (inch)
0
1
2
3
4
Operating Time (years)

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :

1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"28.8" Degree Nozzle, 22.5 degress rotated from Downhill, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessar to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represnets the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$ Normal blind zone

To place the flaw with repsect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$Val := 2$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.8317$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.661 \cdot 0.12$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$R_o := \frac{od}{2} \qquad R_{id} := \frac{id}{2} \qquad t := R_o - R_{id} \qquad R_m := R_{id} + \frac{t}{2} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$CF_{inhr} := 1.417 \cdot 10^5 \qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad c_0 := \frac{L}{2} \qquad R_t := \frac{R_m}{t}$$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

Stress Input Data

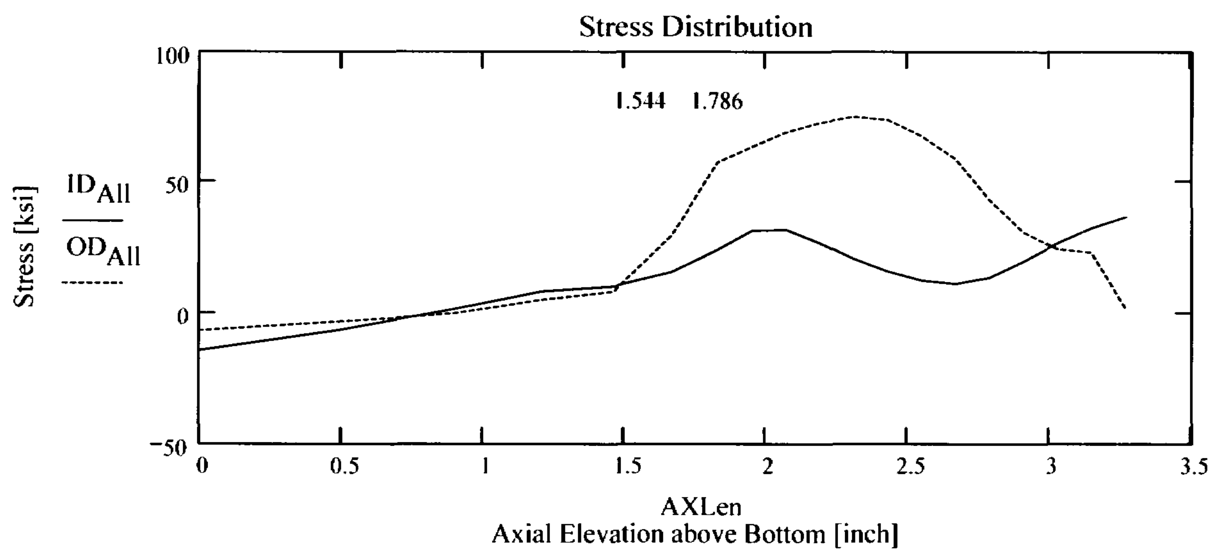
Input all available Nodal stress data in the table below. The column designations are as follows:

Column "0" = Axial distance from minumum to maximum recorded on data sheet(inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-14.21	-11.51	-9.79	-8.24	-6.72
1	0.5	-6.49	-5.19	-4.42	-3.8	-3.18
2	0.89	1.55	1.02	0.56	0.26	-0.08
3	1.21	8.43	7.98	7.2	6.19	5.29
4	1.46	10.25	12.71	12.22	11.35	8.36
5	1.67	15.66	18.34	18.7	20.84	29.7
6	1.83	24.32	24.53	26.71	44.52	57.73
7	1.95	31.5	28.7	31.23	53.02	63.55
8	2.07	31.98	30.11	35.63	59.45	69.03
9	2.19	26.83	29.95	38.37	61.12	72.69
10	2.31	20.84	27.29	38.5	59.95	75.04
11	2.43	15.99	24.67	38.16	58.17	73.85

$AXLen := AllData^{\langle 0 \rangle}$ $\qquad ID_{All} := AllData^{\langle 1 \rangle}$ $\qquad OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\mathrm{Data} := \begin{pmatrix} 0 & -14.205 & -11.506 & -9.79 & -8.243 & -6.722 \\ 0.495 & -6.493 & -5.188 & -4.425 & -3.796 & -3.176 \\ 0.892 & 1.555 & 1.021 & 0.565 & 0.257 & -0.076 \\ 1.21 & 8.43 & 7.98 & 7.199 & 6.186 & 5.292 \\ 1.464 & 10.247 & 12.709 & 12.22 & 11.35 & 8.364 \\ 1.668 & 15.665 & 18.335 & 18.703 & 20.835 & 29.697 \\ 1.832 & 24.321 & 24.532 & 26.71 & 44.525 & 57.729 \\ 1.951 & 31.496 & 28.696 & 31.228 & 53.015 & 63.555 \\ 2.071 & 31.975 & 30.109 & 35.633 & 59.449 & 69.026 \\ 2.19 & 26.833 & 29.946 & 38.369 & 61.124 & 72.691 \\ 2.31 & 20.84 & 27.287 & 38.5 & 59.952 & 75.043 \end{pmatrix}$$

$\mathrm{Axl} := \mathrm{Data}^{\langle 0 \rangle}$ $\quad \mathrm{MD} := \mathrm{Data}^{\langle 3 \rangle}$ $\quad \mathrm{ID} := \mathrm{Data}^{\langle 1 \rangle}$ $\quad \mathrm{TQ} := \mathrm{Data}^{\langle 4 \rangle}$ $\quad \mathrm{QT} := \mathrm{Data}^{\langle 2 \rangle}$ $\quad \mathrm{OD} := \mathrm{Data}^{\langle 5 \rangle}$

$R_{ID} := \mathrm{regress}(\mathrm{Axl}, \mathrm{ID}, 3)$ $\quad R_{QT} := \mathrm{regress}(\mathrm{Axl}, \mathrm{QT}, 3)$

$R_{OD} := \mathrm{regress}(\mathrm{Axl}, \mathrm{OD}, 3)$

$R_{MD} := \mathrm{regress}(\mathrm{Axl}, \mathrm{MD}, 3)$ $\quad R_{TQ} := \mathrm{regress}(\mathrm{Axl}, \mathrm{TQ}, 3)$

$$FL_{Cntr} := \begin{array}{|l} Ref_{Point} - c_0 \;\; \text{if } Val = 1 \\ Ref_{Point} \;\; \text{if } Val = 2 \\ Ref_{Point} + c_0 \;\; \text{otherwise} \end{array}$$

Flaw center Location Location above Nozzle Bottom

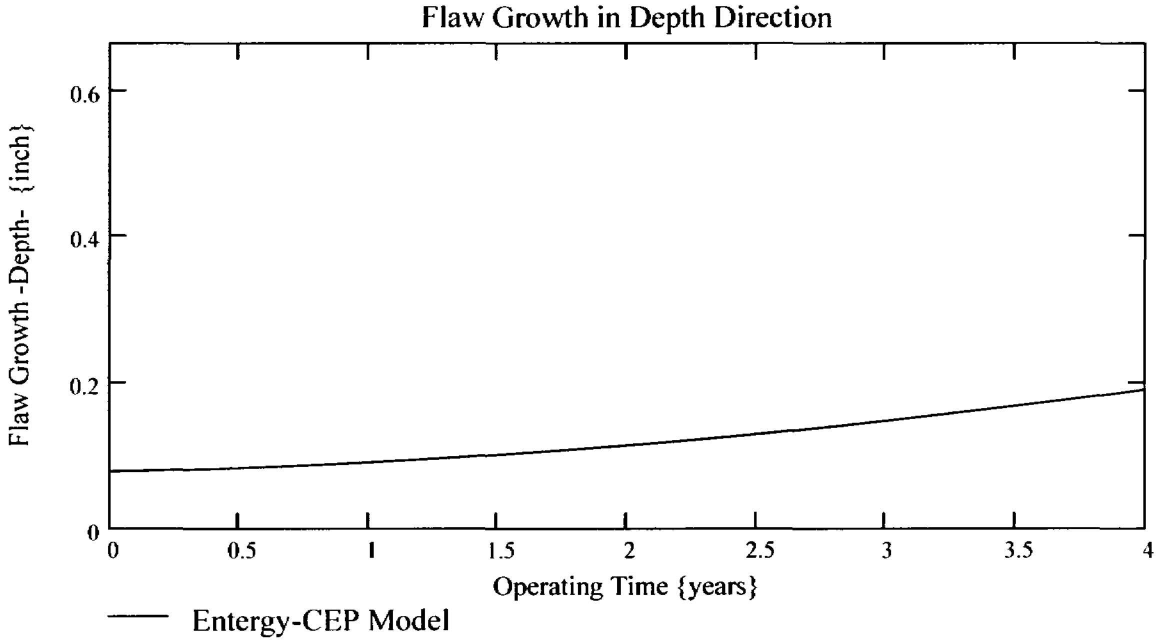
$U_{Tip} := FL_{Cntr} + c_0$

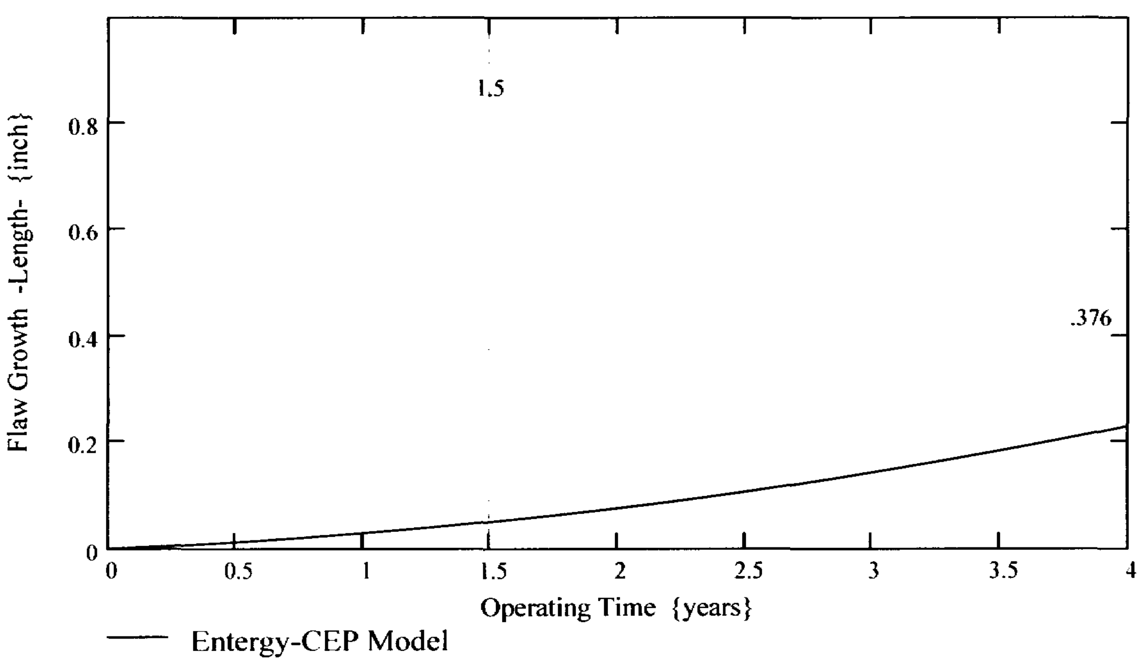
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

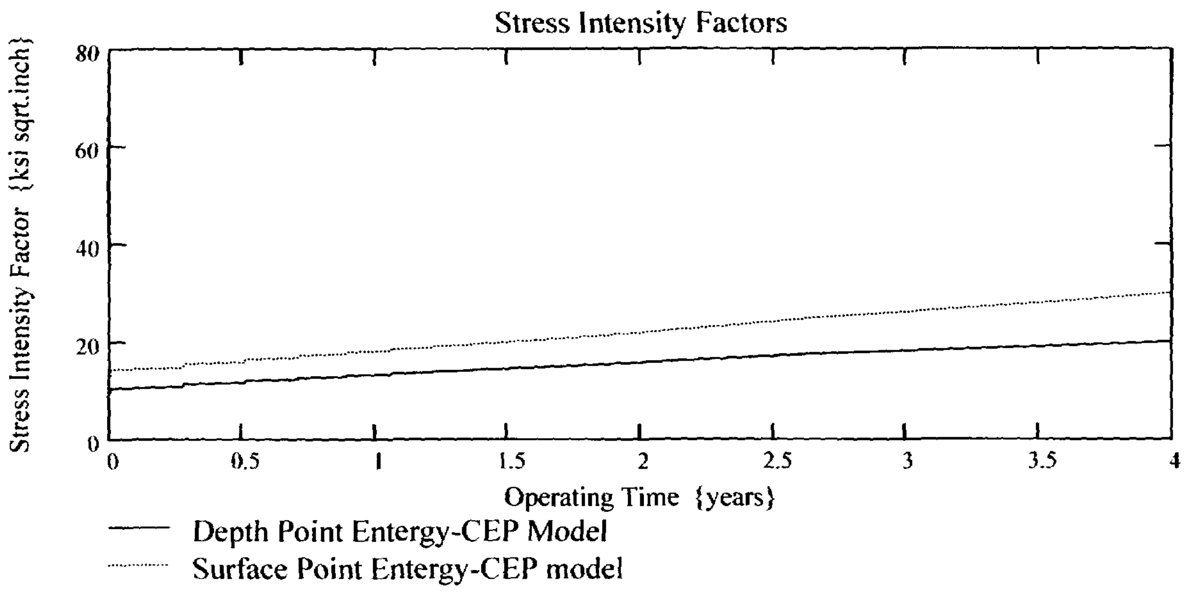
No User Input is required beyond this Point

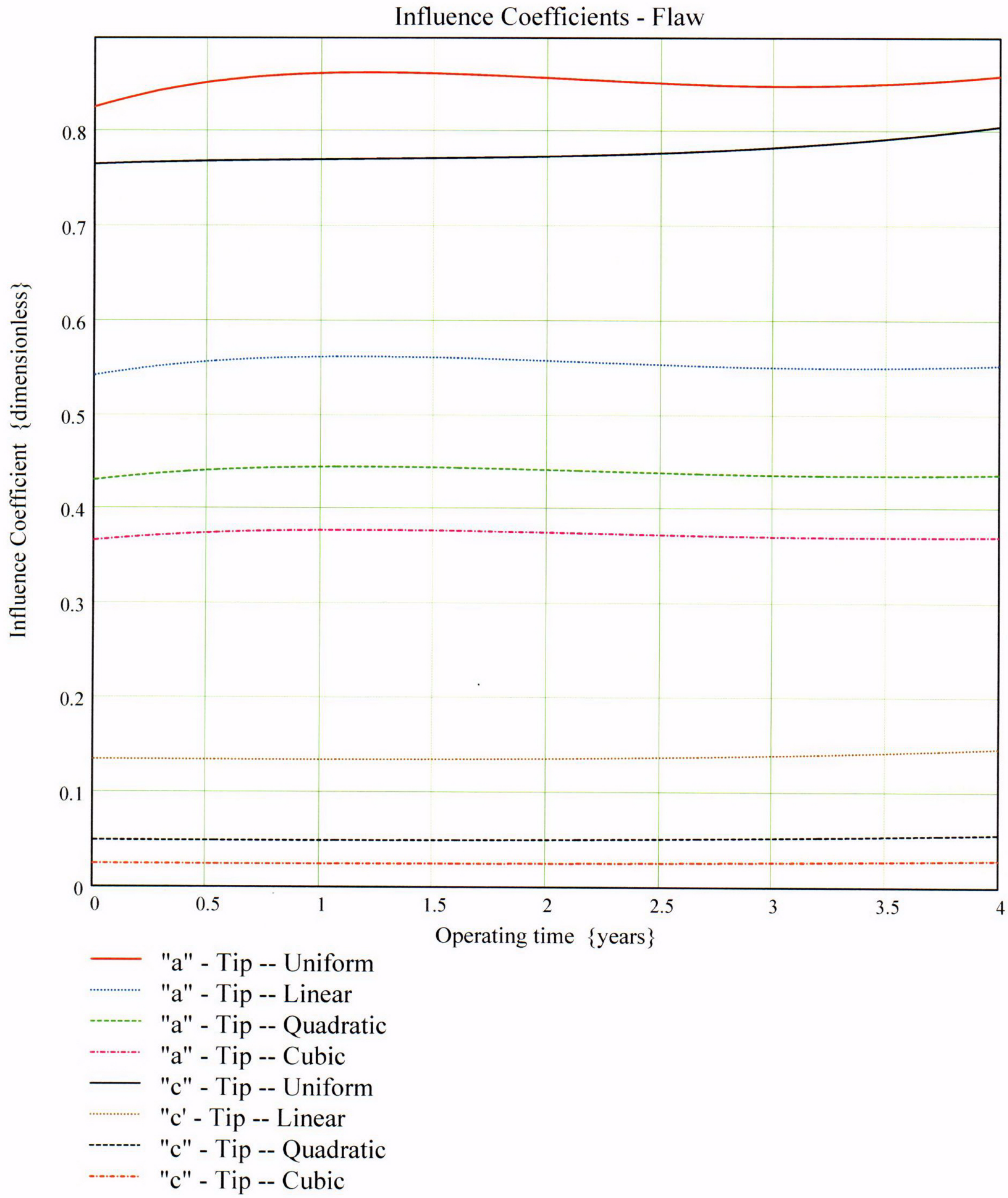
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.128$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

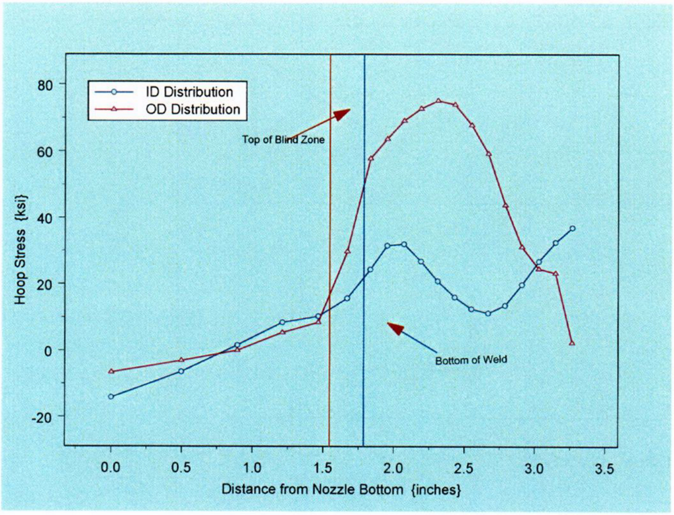
0.827
0.827
0.827
0.827
0.827
0.828
0.828
0.828
0.828
0.828
0.828
0.829
0.829
0.829
0.829
0.829

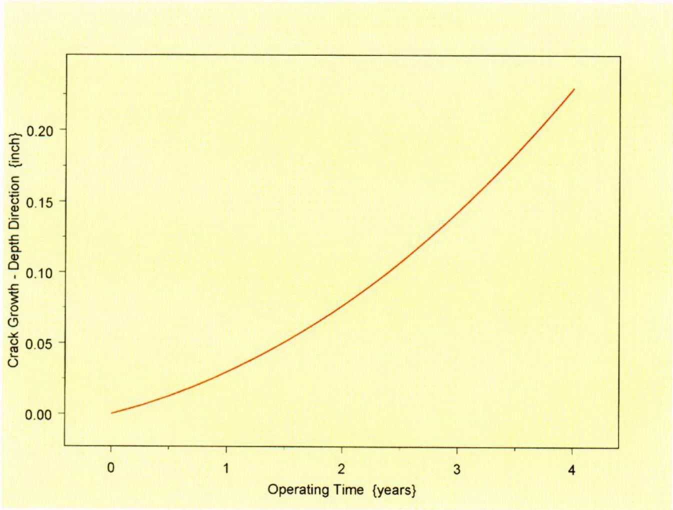
$CGR_{sambi_{(k,6)}} =$

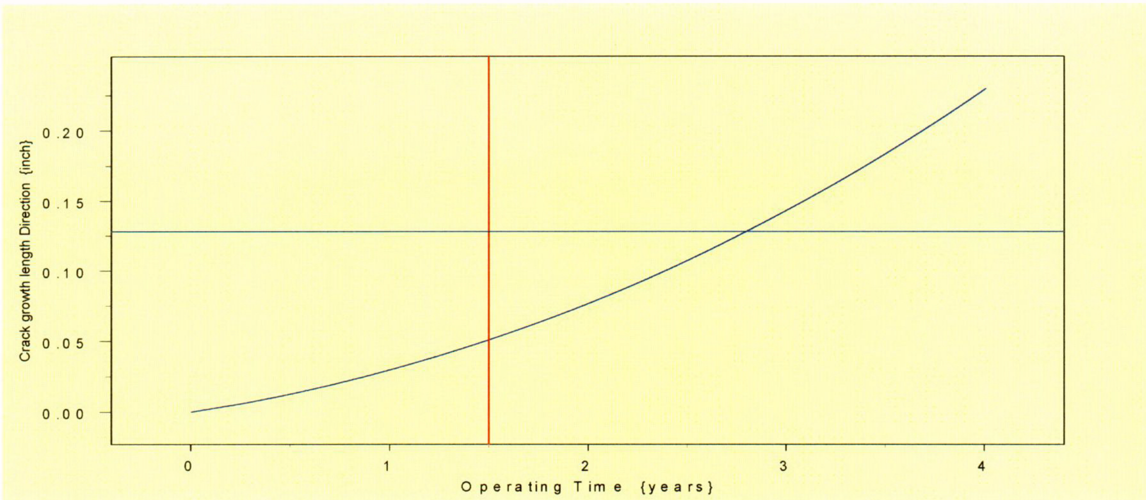
13.267
14.419
14.423
14.427
14.43
14.434
14.437
14.441
14.445
14.448
14.452
14.455
14.459
14.462
14.466
14.47

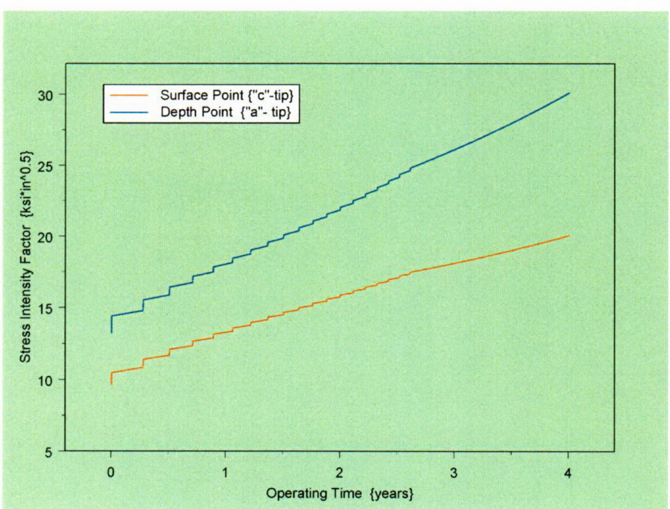
$CGR_{sambi_{(k,5)}} =$

9.64
10.474
10.478
10.482
10.485
10.489
10.493
10.497
10.5
10.504
10.508
10.512
10.516
10.519
10.523
10.527


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
80
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance from Nozzle Bottom {inches}


Crack Growth - Depth Direction {inch}
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
Operating Time {years}


Crack growth length Direction {inch}
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
30
25
20
15
10
5
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :
1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49" Degree Nozzle, Downhill Azimuth, Augmented Analysis 1.043" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

OD Surface Flaw

This Attachment is Intentionally Blank

Sat Aug 09 10:21:18 AM 2003

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"0"degree Nozzle, All Azimuth, Augmented Analysis
1.25 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** .
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.25$ Location of Blind Zone above nozzle bottom (inch)

Note: *Lowered BZ. This allows a Freespan of 0.546 inch to bottom of weld*

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 1.796$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := .794$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$v := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$

$$Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^{5}$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

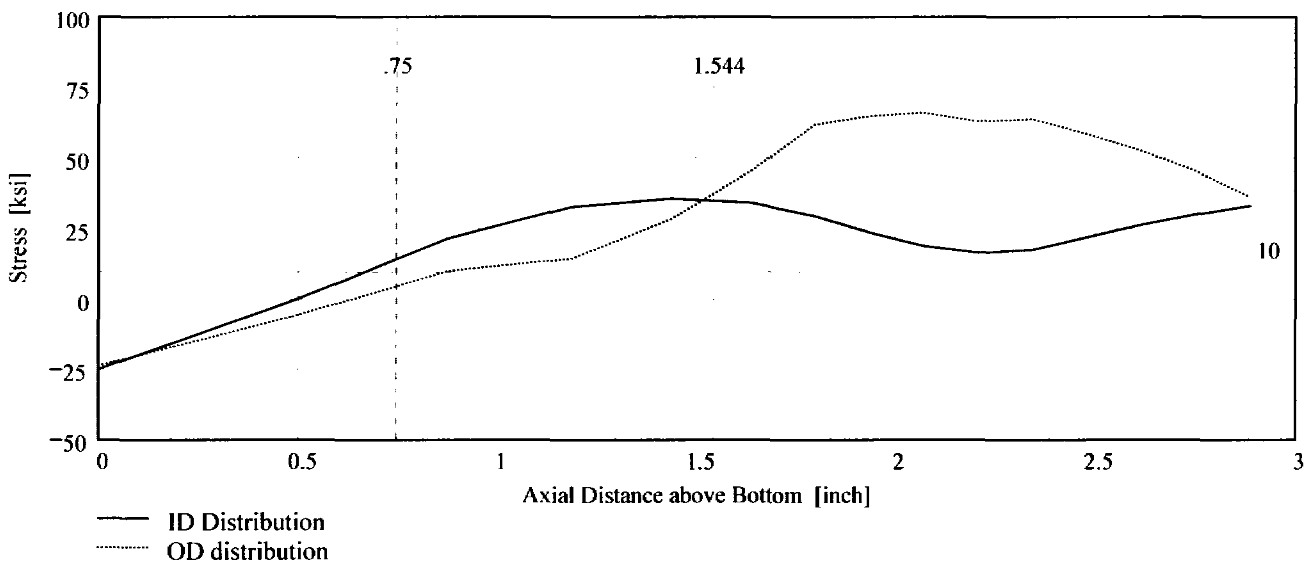
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-25.09	-27.55	-27.79	-25.62	-23.76
1	0.49	-0.56	-0.54	-2.11	-4.85	-6.16
2	0.87	21.52	18.64	17.12	14.84	10.09
3	1.19	32.75	28.49	24.14	19.64	14.45
4	1.44	35.67	29.6	26.17	25.59	28.42
5	1.64	34.24	29.57	28.29	35.41	45.38
6	1.8	29.45	29.81	31.39	43.34	61.71
7	1.93	23.67	26.5	33.26	47.61	64.65
8	2.07	18.93	24.56	33.97	49.07	65.88
9	2.2	16.54	22.85	34.79	49.52	62.8
10	2.34	17.56	22.68	33.81	47.49	63.56

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $\quad AllID := Data_{All}^{\langle 1 \rangle}$ $\quad AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled Data$_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\mathrm{Data} := \begin{pmatrix} 0 & -25.088 & -27.546 & -27.787 & -25.624 & -23.763 \\ 0.485 & -0.563 & -0.539 & -2.111 & -4.851 & -6.157 \\ 0.874 & 21.515 & 18.635 & 17.122 & 14.843 & 10.089 \\ 1.186 & 32.751 & 28.494 & 24.136 & 19.645 & 14.45 \\ 1.436 & 35.667 & 29.598 & 26.166 & 25.589 & 28.417 \\ 1.635 & 34.244 & 29.574 & 28.286 & 35.408 & 45.379 \\ 1.796 & 29.45 & 29.814 & 31.385 & 43.337 & 61.713 \\ 1.932 & 23.674 & 26.502 & 33.261 & 47.609 & 64.65 \\ 2.068 & 18.928 & 24.564 & 33.968 & 49.071 & 65.876 \\ 2.204 & 16.541 & 22.854 & 34.789 & 49.525 & 62.795 \end{pmatrix}$$

$\mathrm{Axl} := \mathrm{Data}^{\langle 0 \rangle}$ $\mathrm{ID} := \mathrm{Data}^{\langle 1 \rangle}$ $\mathrm{OD} := \mathrm{Data}^{\langle 5 \rangle}$

$R_{ID} := \mathrm{regress}(\mathrm{Axl}, \mathrm{ID}, 3)$ $R_{OD} := \mathrm{regress}(\mathrm{Axl}, \mathrm{OD}, 3)$

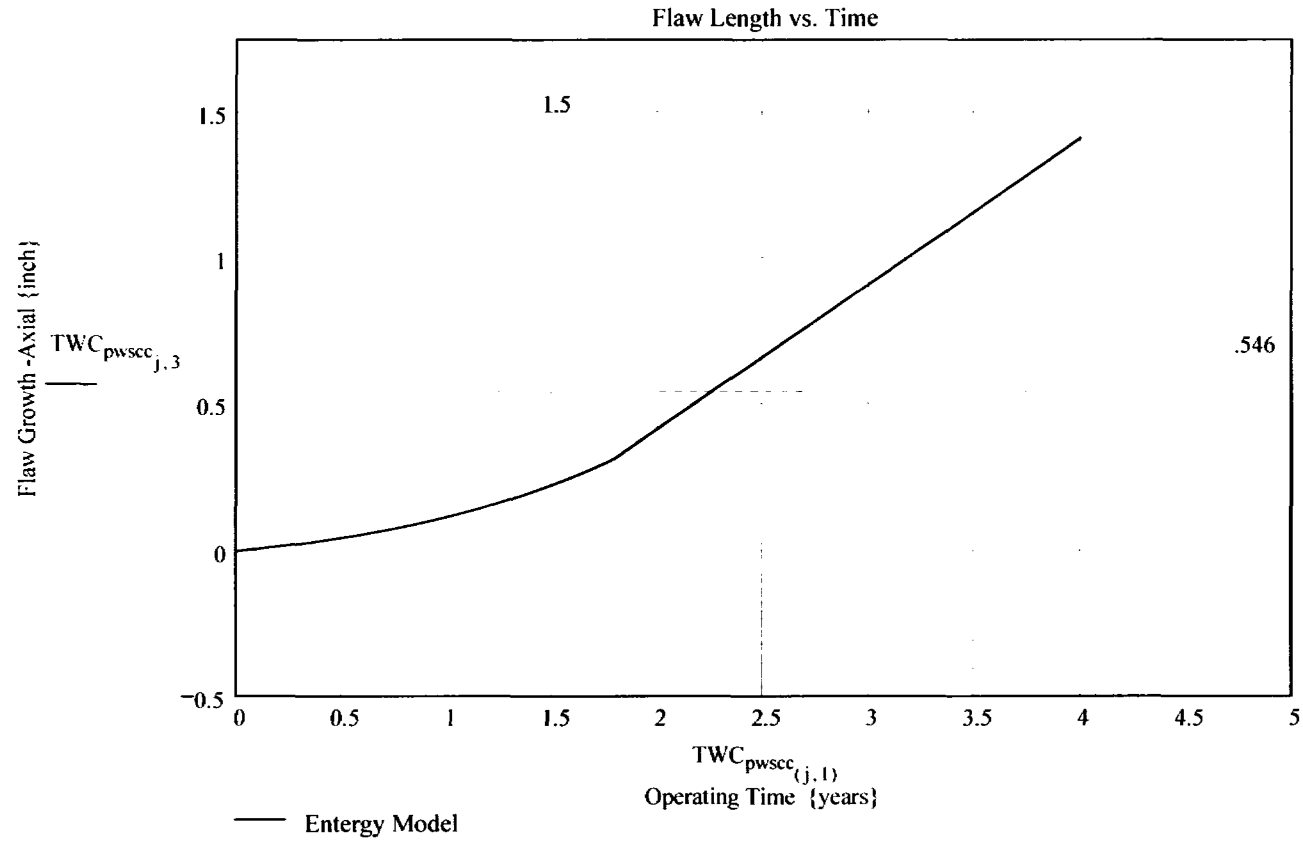
$FL_{Cntr} := BZ - l$ Flaw Center above Nozzle Bottom

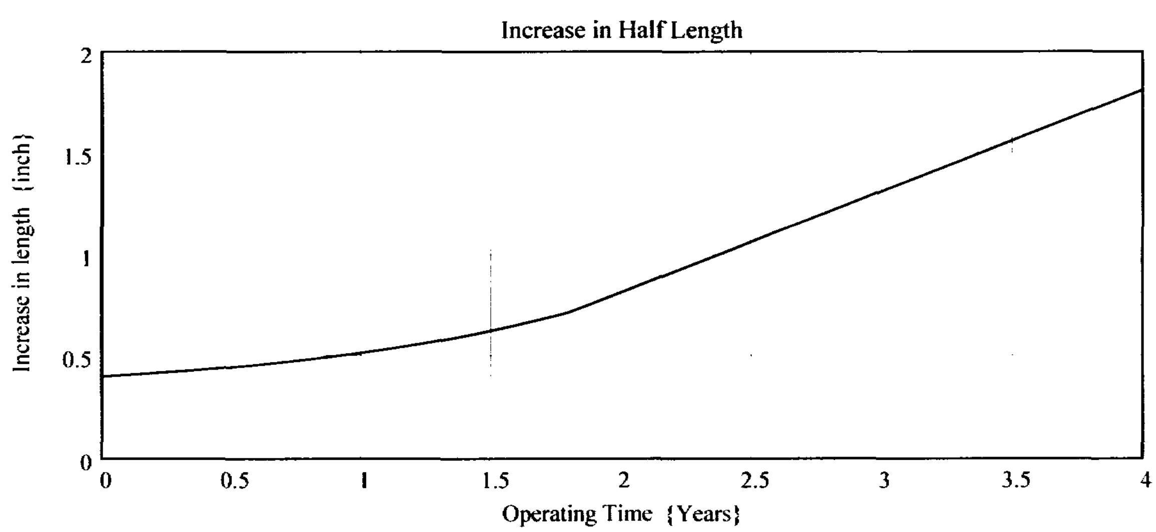
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

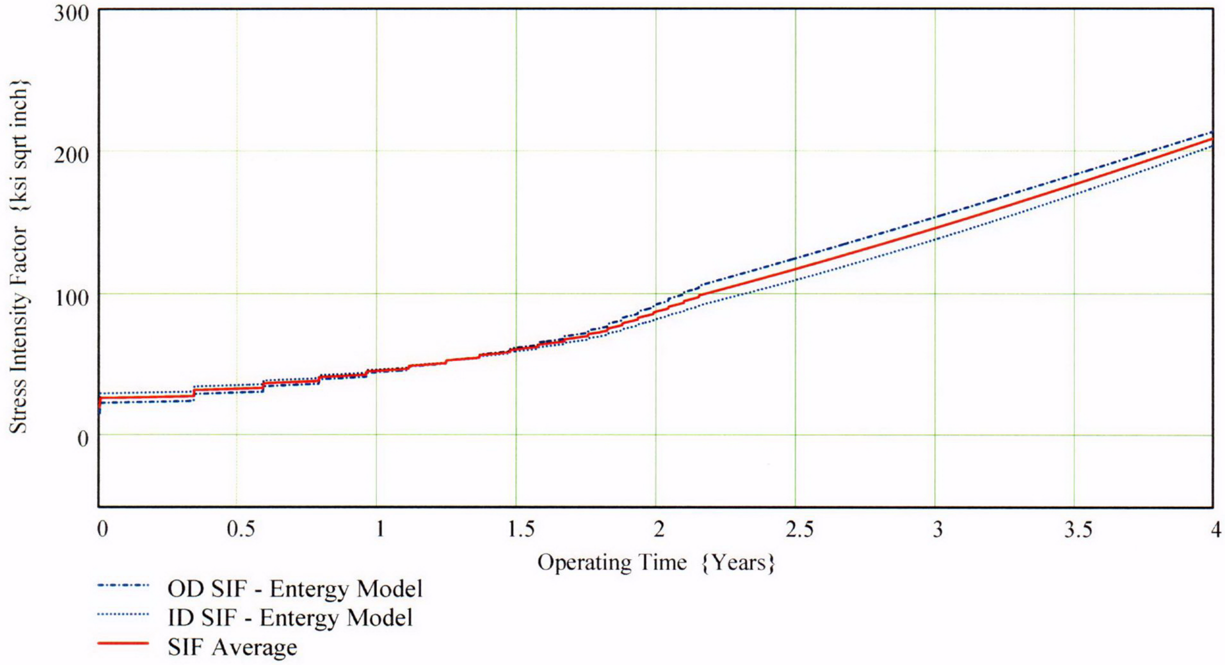
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

$Prop_{Length} = 0.546$






300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$

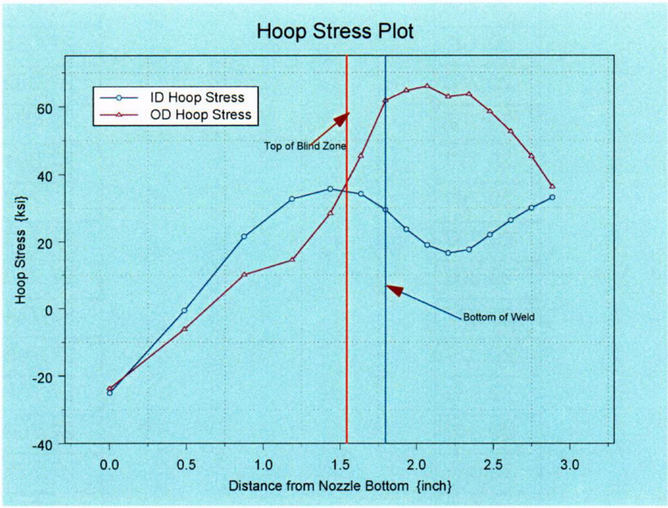
15.871
23.129
23.139
23.149
23.159
23.169
23.179
23.189
23.199
23.21
23.22
23.23
23.24
23.25
23.26
23.271

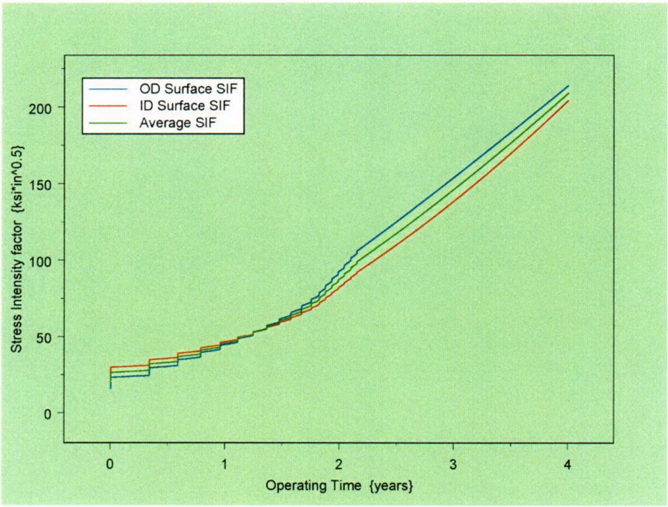
$TWC_{pwscc_{(j,7)}} =$

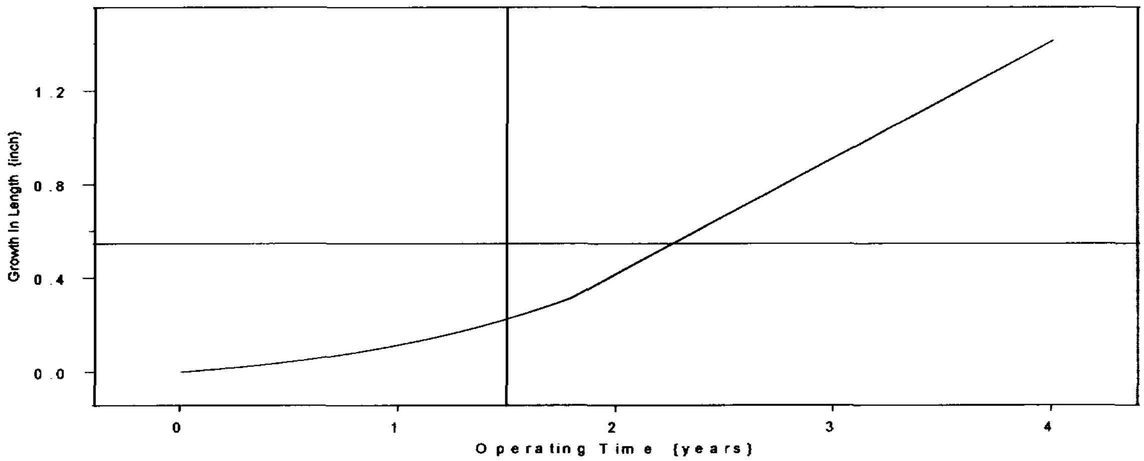
24.273
29.738
29.748
29.758
29.768
29.777
29.787
29.797
29.807
29.817
29.827
29.837
29.847
29.857
29.867
29.878

$TWC_{pwscc_{(j,8)}} =$

21.089
27.647
27.658
27.669
27.68
27.691
27.702
27.713
27.723
27.734
27.745
27.756
27.767
27.778
27.789
27.8


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
Distance from Nozzle Bottom {inch}
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
Operating Time {years}
200
150
100
50
0
0
1
2
3
4


1.2
0.8
0.4
0.0
Growth in Length (inch)
0
1
2
3
4
Operating Time (years)

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8"Degree Nozzle, Downhill Azimuth, Augmented Analysis
1.25 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** .
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg. Blind Zone) above the nozzle bottom in inches.

$BZ := 1.25$ Location of Blind Zone above nozzle bottom (inch)

Note :- *BZ lowered; This increases the freespan length to 0.536 inch*

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 1.786$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := .794$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$v := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$

$$Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^5$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

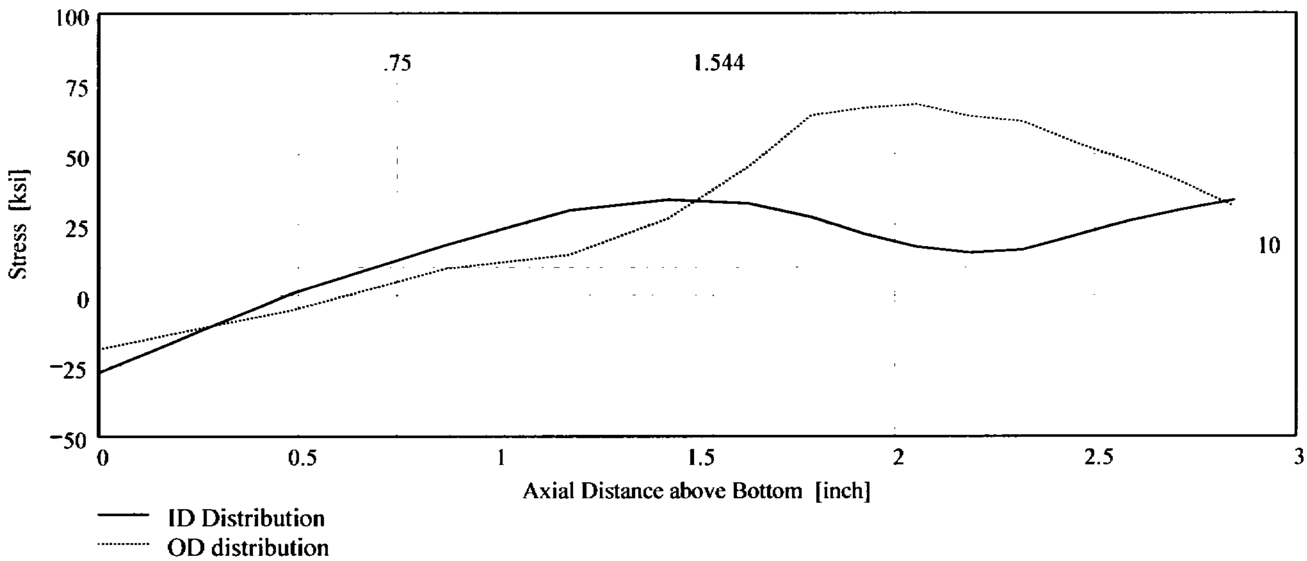
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-27.4	-24.36	-22.21	-20.41	-18.98
1	0.48	0.63	-1.49	-3.6	-4.44	-5.27
2	0.87	17.66	16.42	14.61	12.41	9.38
3	1.18	29.8	26.05	22.72	18.95	14.2
4	1.43	33.62	27.79	24.8	24.32	26.99
5	1.63	32.36	28.47	27.59	34.28	45.1
6	1.79	27.39	28.92	31.39	43.88	63.72
7	1.92	21.5	25.56	33.55	48.09	66.36
8	2.05	16.94	23.79	34.06	49.47	67.67
9	2.18	14.83	22.26	34.78	49.05	63.38

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $\quad$ $AllID := Data_{All}^{\langle 1 \rangle}$ $\quad$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -27.404 & -24.356 & -22.209 & -20.407 & -18.978 \\ 0.483 & 0.633 & -1.486 & -3.599 & -4.44 & -5.268 \\ 0.87 & 17.665 & 16.422 & 14.61 & 12.415 & 9.376 \\ 1.18 & 29.798 & 26.049 & 22.723 & 18.95 & 14.201 \\ 1.428 & 33.623 & 27.792 & 24.8 & 24.321 & 26.989 \\ 1.627 & 32.364 & 28.469 & 27.591 & 34.284 & 45.104 \\ 1.786 & 27.394 & 28.918 & 31.388 & 43.882 & 63.718 \\ 1.919 & 21.498 & 25.556 & 33.55 & 48.089 & 66.365 \\ 2.051 & 16.944 & 23.793 & 34.064 & 49.472 & 67.672 \\ 2.183 & 14.834 & 22.263 & 34.779 & 49.055 & 63.377 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{OD} := regress(Axl, OD, 3)$

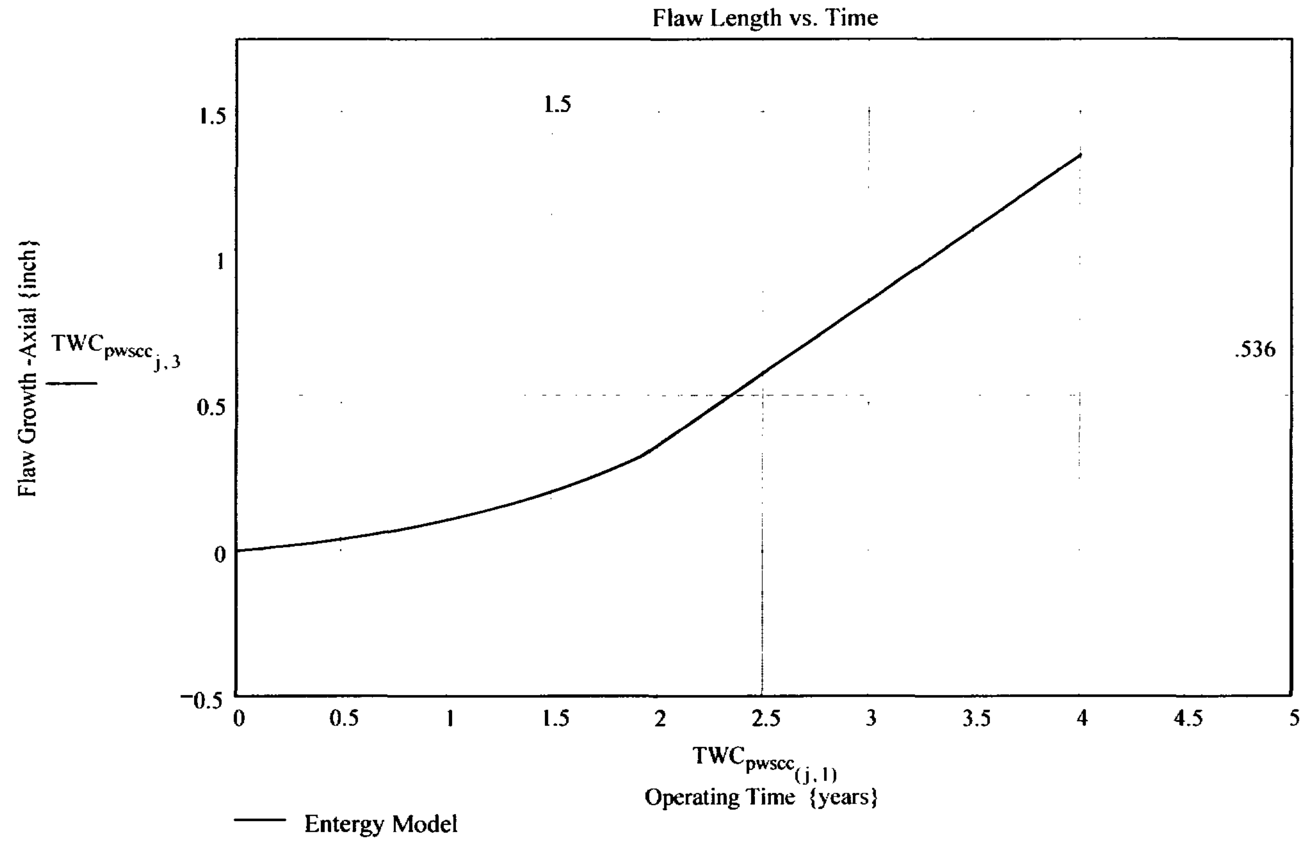
$FL_{Cntr} := BZ - l$ Flaw Center above Nozzle Bottom

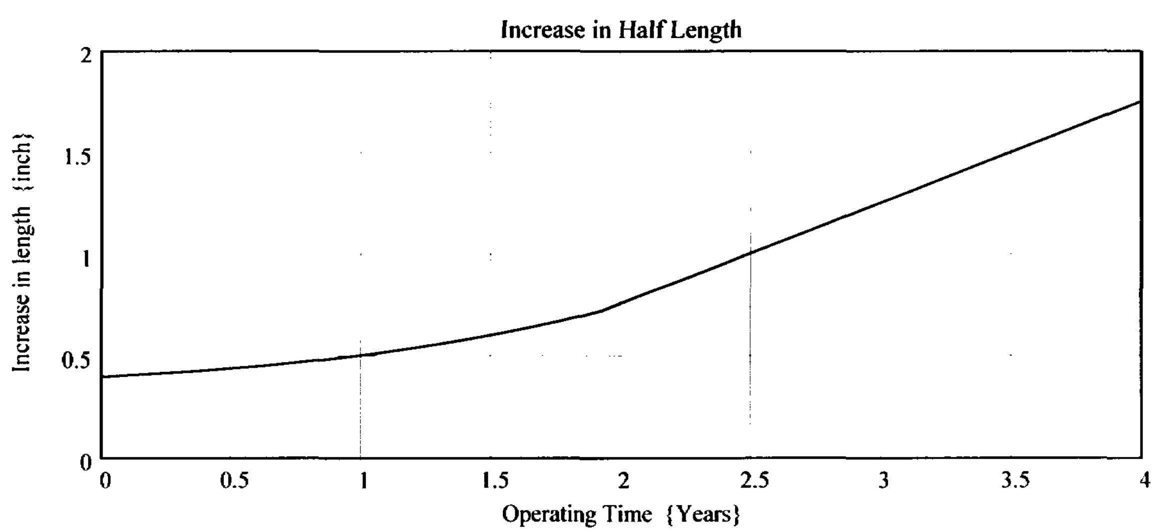
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

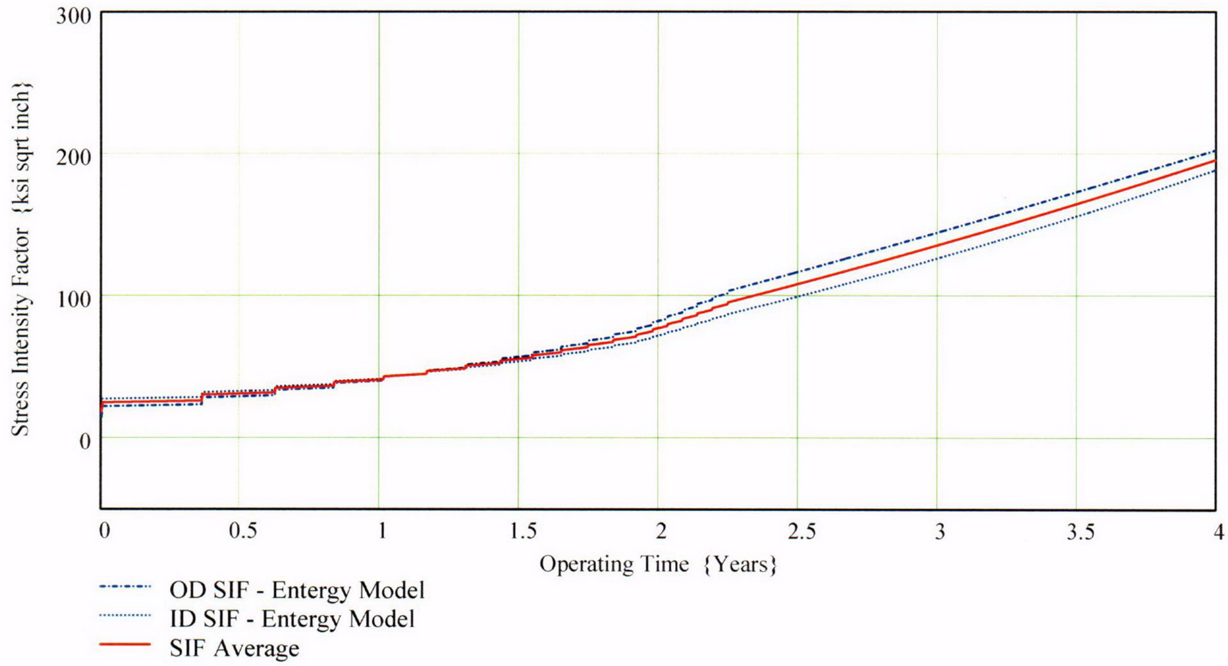
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

$Prop_{Length} = 0.536$






300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$

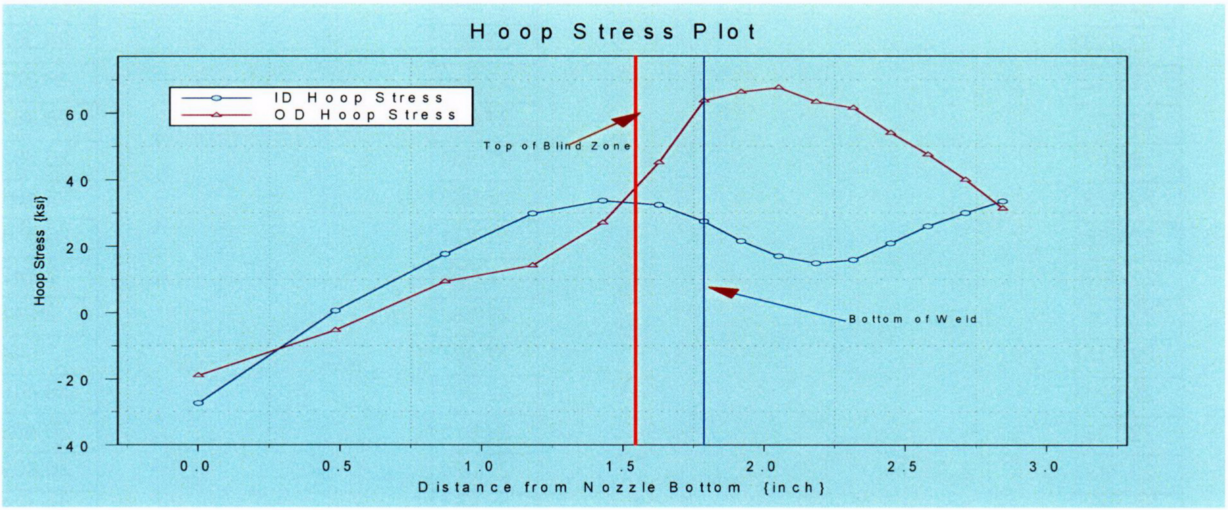
15.478
22.634
22.643
22.652
22.661
22.67
22.679
22.688
22.697
22.706
22.715
22.724
22.733
22.742
22.751
22.76

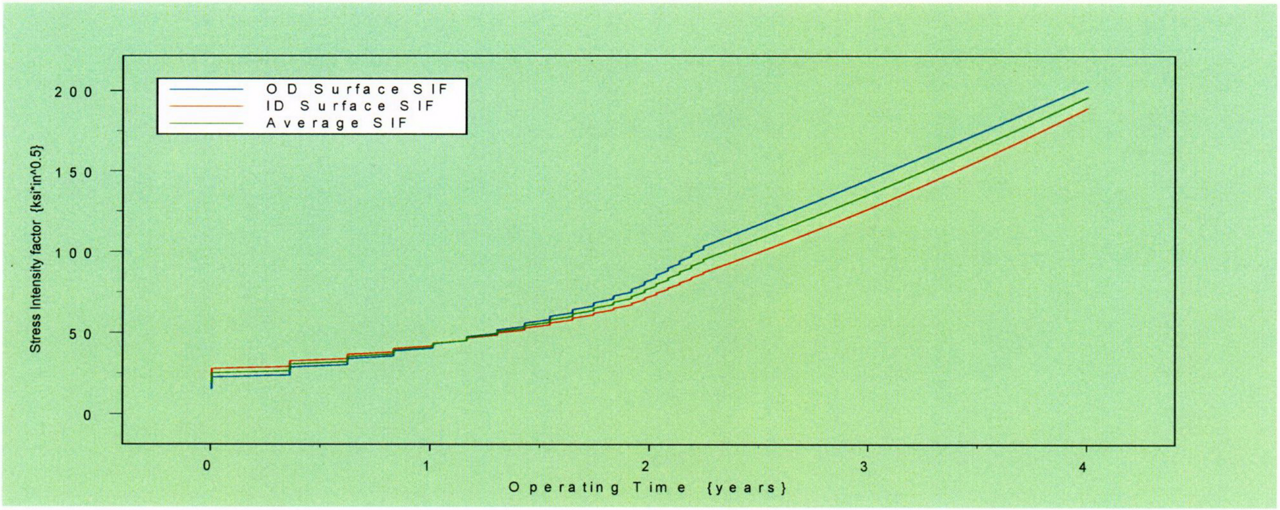
$TWC_{pwscc_{(j,7)}} =$

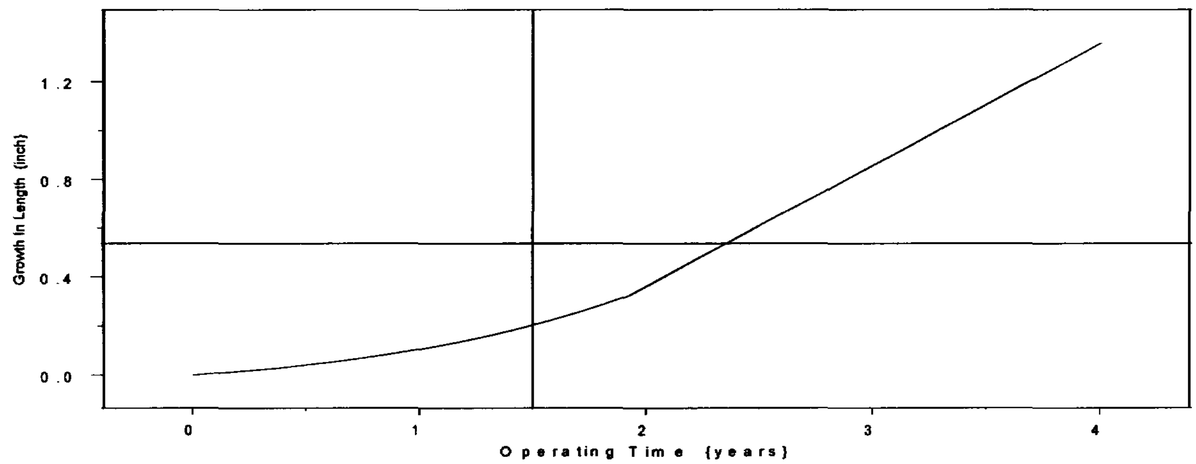
22.524
27.819
27.828
27.836
27.845
27.854
27.863
27.871
27.88
27.889
27.897
27.906
27.915
27.924
27.932
27.941

$TWC_{pwscc_{(j,8)}} =$

19.938
26.353
26.363
26.372
26.382
26.392
26.401
26.411
26.42
26.43
26.44
26.449
26.459
26.469
26.478
26.488


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
200
150
100
50
0
0
1
2
3
4
Operating Time {years}


1.2
0.8
0.4
0.0
Growth In Length (inch)
0
1
2
3
4
Operating Time (years)

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :

1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49" Degree Nozzle, 22.5 degree from Downhill Azimuth, Augmented Analysis; 1.30" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessar to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represnets the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.3$ *This is the reduced Blind zone for augmented analysis; permits a 0.2504 inch free span & 0.09 inch Propogation Length*

To place the flaw with repsect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$Val := 2$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.5504$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.661 \cdot 0.12$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$R_o := \frac{od}{2}$ $\quad R_{id} := \frac{id}{2}$ $\quad t := R_o - R_{id}$ $\quad R_m := R_{id} + \frac{t}{2}$ $\quad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\quad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\quad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right|$ $\quad c_0 := \frac{L}{2}$ $\quad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

Stress Input Data

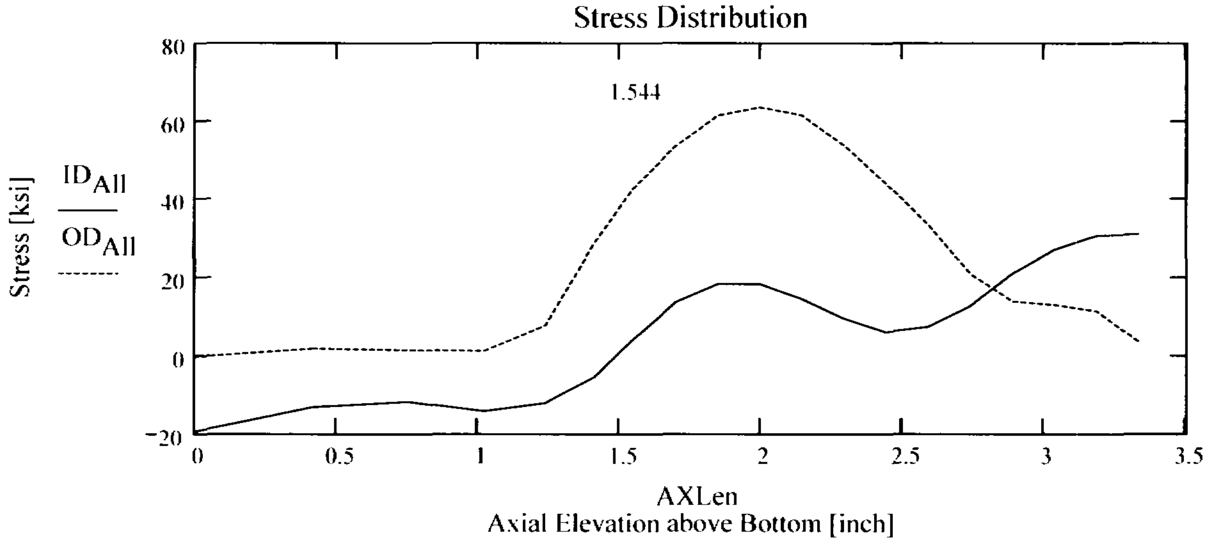
Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum to maximum recorded on data sheet(inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-19.3	-12.52	-8.3	-4.31	-0.29
1	0.42	-13.15	-8.57	-4.68	-1.25	1.83
2	0.75	-11.83	-6.96	-2.68	0.03	1.46
3	1.02	-14.15	-8.31	-3.17	1.1	1.22
4	1.24	-12.13	-6.55	0	5.78	7.86
5	1.41	-5.38	-2.41	7.5	23.29	28.72
6	1.55	4.33	6.48	17.84	35.67	42.75
7	1.7	13.64	15.67	27.16	40.65	53.56
8	1.85	18.3	21.2	32.42	50.34	61.38
9	2	18.32	22.29	34.21	53.26	63.46
10	2.14	14.52	21.82	35.09	51.48	61.5
11	2.29	9.62	20.82	34.51	47.88	53.88
12	2.44	6.18	19.92	32.26	40.25	44.06

$AXLen := AllData^{\langle 0 \rangle}$ $\qquad ID_{All} := AllData^{\langle 1 \rangle}$ $\qquad OD_{All} := AllData^{\langle 5 \rangle}$

Stress Distribution



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -19.301 & -12.523 & -8.304 & -4.314 & -0.289 \\ 0.419 & -13.153 & -8.572 & -4.68 & -1.255 & 1.834 \\ 0.755 & -11.834 & -6.958 & -2.685 & 0.028 & 1.463 \\ 1.024 & -14.146 & -8.315 & -3.168 & 1.103 & 1.221 \\ 1.239 & -12.132 & -6.552 & 3.002\times 10^{-3} & 5.78 & 7.858 \\ 1.412 & -5.38 & -2.413 & 7.498 & 23.29 & 28.718 \\ 1.55 & 4.331 & 6.478 & 17.842 & 35.67 & 42.747 \\ 1.699 & 13.644 & 15.667 & 27.164 & 40.65 & 53.563 \\ 1.847 & 18.304 & 21.201 & 32.424 & 50.345 & 61.379 \\ 1.996 & 18.316 & 22.292 & 34.208 & 53.258 & 63.464 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{vmatrix} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{vmatrix}$$

Flaw center Location Location above Nozzle Bottom

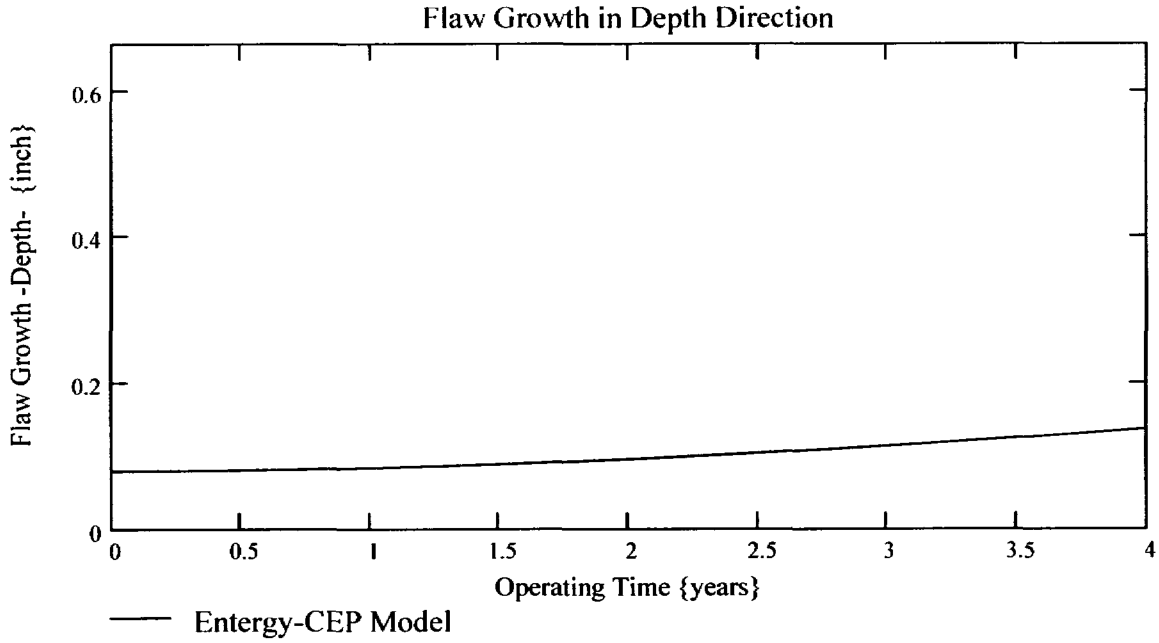
$U_{Tip} := FL_{Cntr} + c_0$

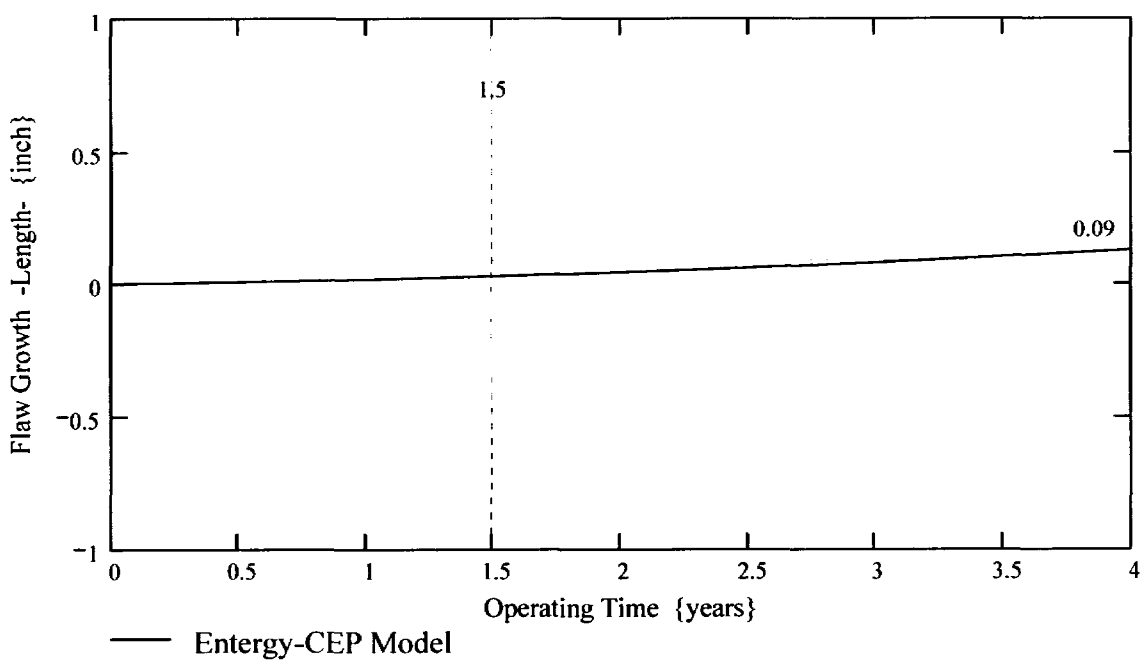
$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$

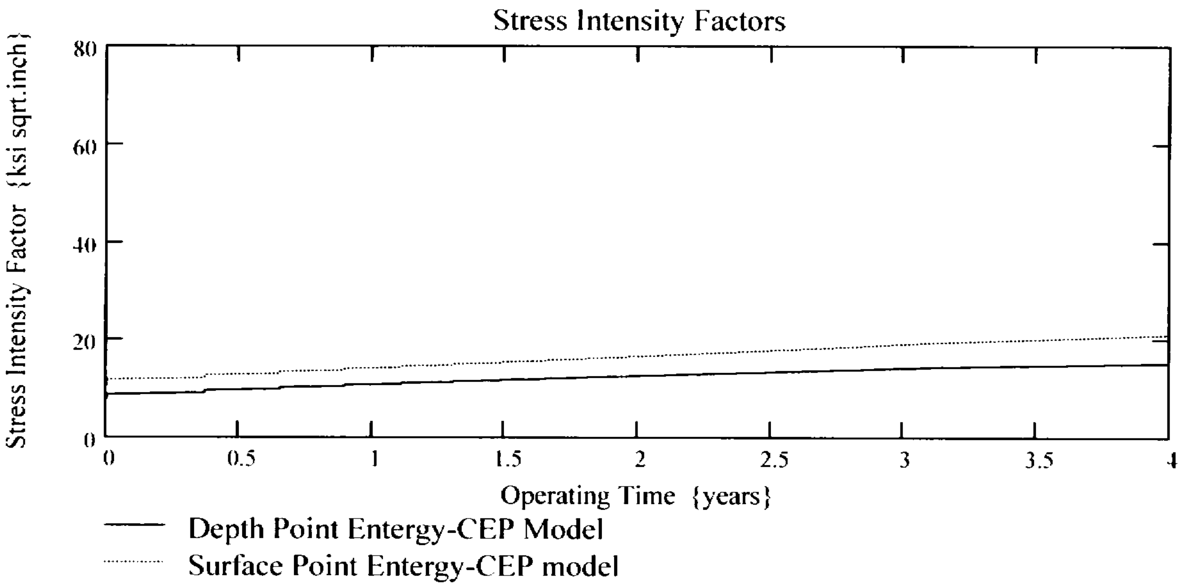
No User Input is required beyond this Point

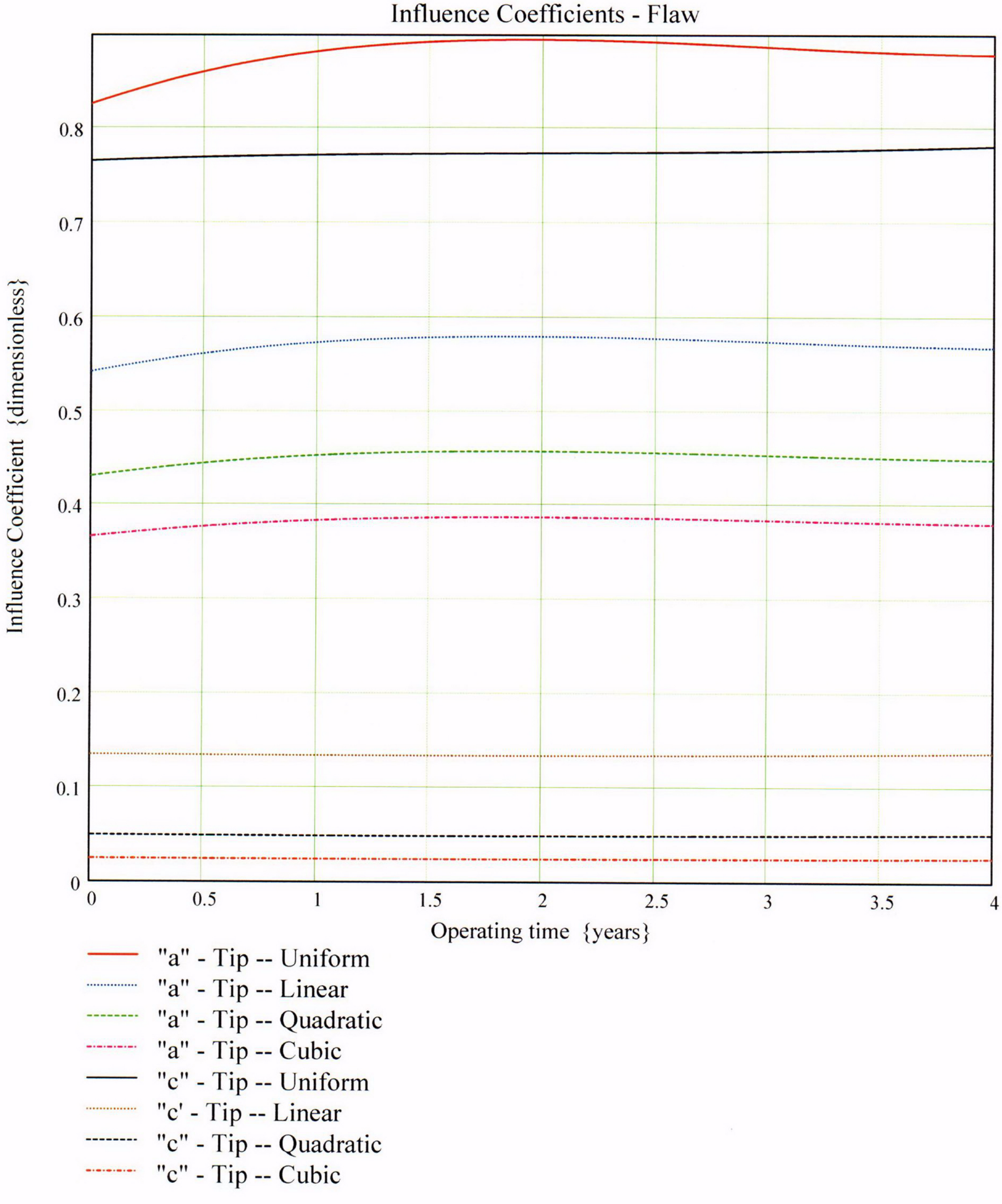
Sat Aug 09 10:21:18 AM 2003

$\text{Prop}_{\text{Length}} = 0.09$

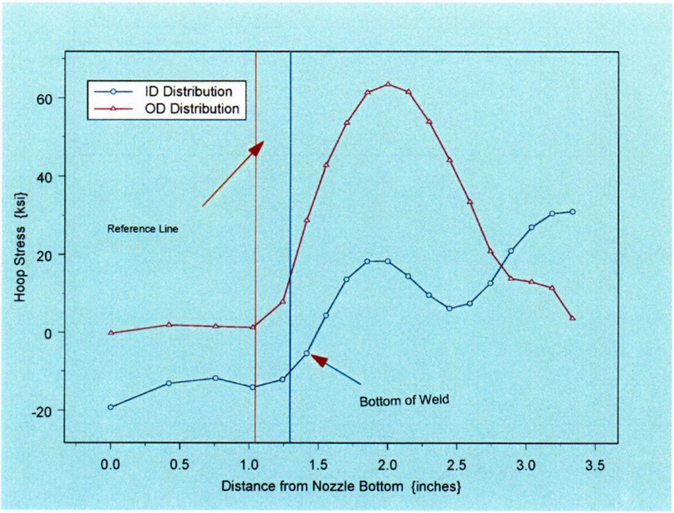


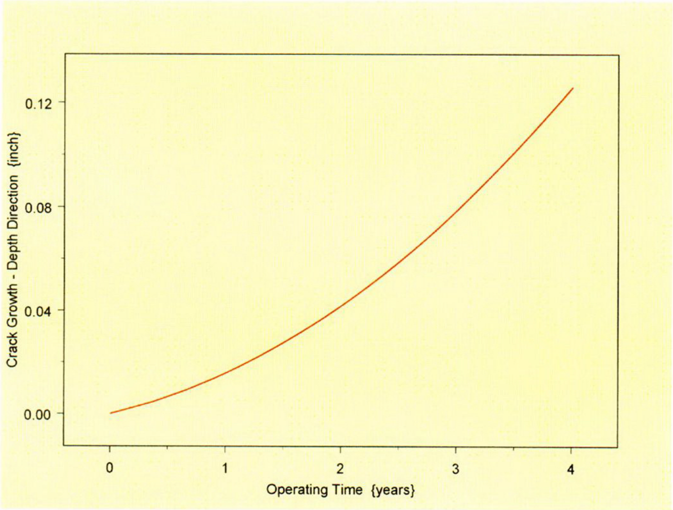


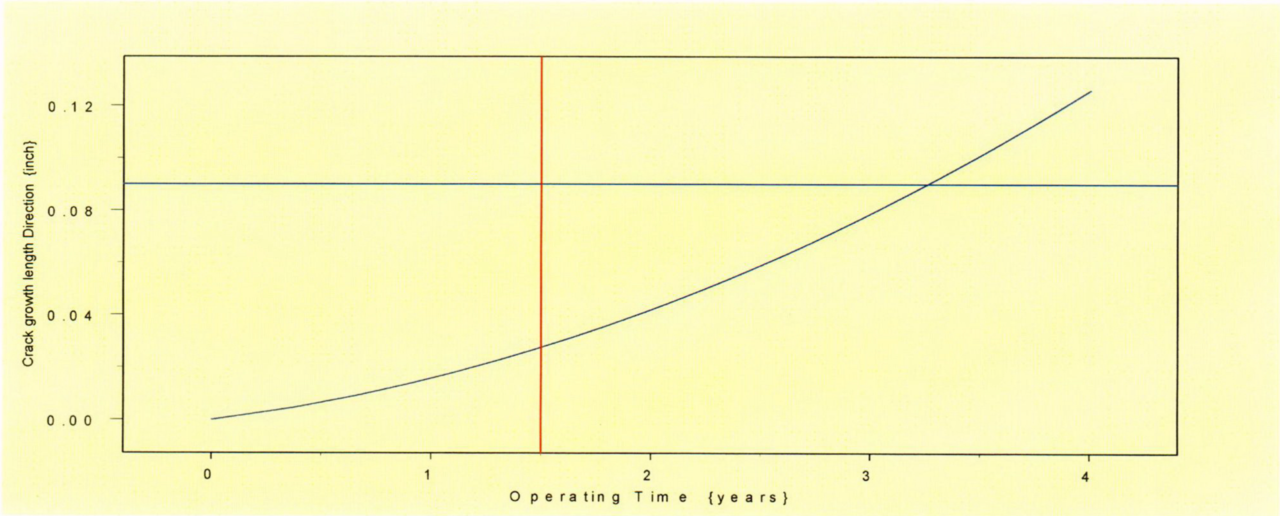

Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model

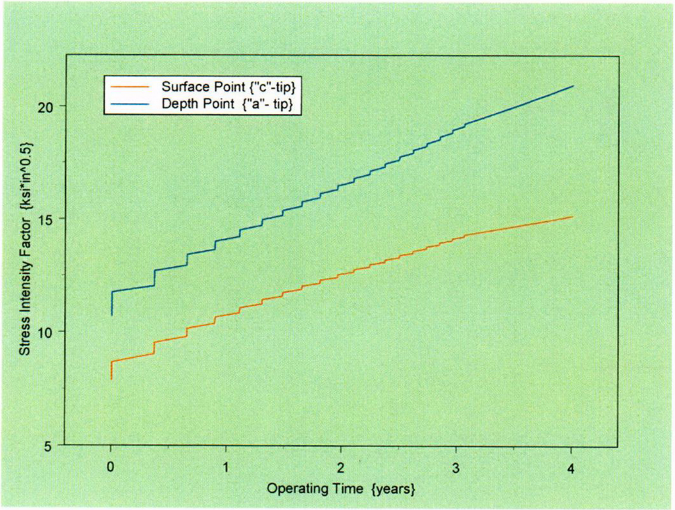

Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$	$CGR_{sambi_{(k,6)}} =$	$CGR_{sambi_{(k,5)}} =$
0.827	10.711	7.9
0.827	11.761	8.672
0.827	11.763	8.674
0.827	11.766	8.677
0.827	11.768	8.68
0.828	11.77	8.683
0.828	11.772	8.685
0.828	11.774	8.688
0.828	11.776	8.691
0.828	11.778	8.693
0.829	11.78	8.696
0.829	11.782	8.699
0.829	11.784	8.702
0.829	11.786	8.704
0.829	11.788	8.707
0.83	11.79	8.71


ID Distribution
OD Distribution
Reference Line
Bottom of Weld
Hoop Stress {ksi}
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance from Nozzle Bottom {inches}


Crack Growth - Depth Direction {inch}
0.12
0.08
0.04
0.00
0
1
2
3
4
Operating Time {years}


0.12
0.08
0.04
0.00
Crack growth length Direction {inch}
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
20
15
10
5
Stress Intensity Factor {ksi*in^0.5}
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :

1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49" Degree Nozzle, 45 degree from Downhill Azimuth, Augmented Analysis; 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessar to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represnets the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$ *This is the as-biult Blind Zone*

To place the flaw with repsect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$Val := 2$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 2.1632$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.661 \cdot 0.12$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$R_o := \frac{od}{2}$ $\quad R_{id} := \frac{id}{2}$ $\quad t := R_o - R_{id}$ $\quad R_m := R_{id} + \frac{t}{2}$ $\quad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\quad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\quad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right|$ $\quad c_0 := \frac{L}{2}$ $\quad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

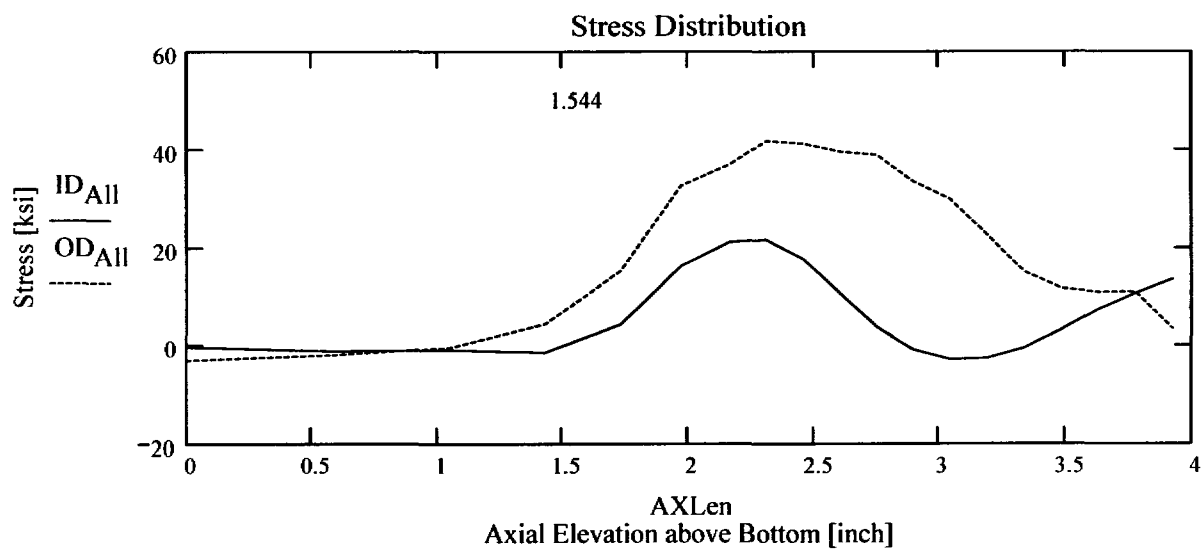
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum to maximum recorded on data sheet(inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-0.41	-1.36	-1.84	-2.37	-3.16
1	0.58	-1.26	-1.49	-1.71	-1.95	-2.07
2	1.05	-1.02	-0.22	0.35	0.52	-0.5
3	1.43	-1.56	0.62	2.58	4.9	4.26
4	1.73	4.17	4.31	8.86	13.38	15.25
5	1.97	16.26	12.54	16.93	28.26	32.67
6	2.16	21.13	17.13	20.09	34.28	36.98
7	2.31	21.59	19.09	21.93	34.05	41.72
8	2.46	17.7	17.82	22.18	34.47	41.21
9	2.6	10.69	14.25	21.11	33.32	39.55
10	2.75	3.59	10.95	19.96	31.01	38.94
11	2.9	-0.98	8.74	18.34	28.35	33.45
12	3.04	-2.94	7.02	18.06	26	29.85

$AXLen := AllData^{\langle 0 \rangle}$ $\qquad ID_{All} := AllData^{\langle 1 \rangle}$ $\qquad OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -0.414 & -1.359 & -1.842 & -2.369 & -3.157 \\ 0.585 & -1.256 & -1.488 & -1.714 & -1.95 & -2.073 \\ 1.053 & -1.023 & -0.223 & 0.347 & 0.516 & -0.495 \\ 1.429 & -1.559 & 0.622 & 2.583 & 4.895 & 4.258 \\ 1.729 & 4.165 & 4.315 & 8.86 & 13.38 & 15.252 \\ 1.97 & 16.258 & 12.541 & 16.926 & 28.26 & 32.667 \\ 2.163 & 21.131 & 17.131 & 20.087 & 34.279 & 36.98 \\ 2.31 & 21.593 & 19.093 & 21.933 & 34.049 & 41.718 \\ 2.457 & 17.702 & 17.82 & 22.18 & 34.468 & 41.213 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{vmatrix} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{vmatrix}$$

Flaw center Location Location above Nozzle Bottom

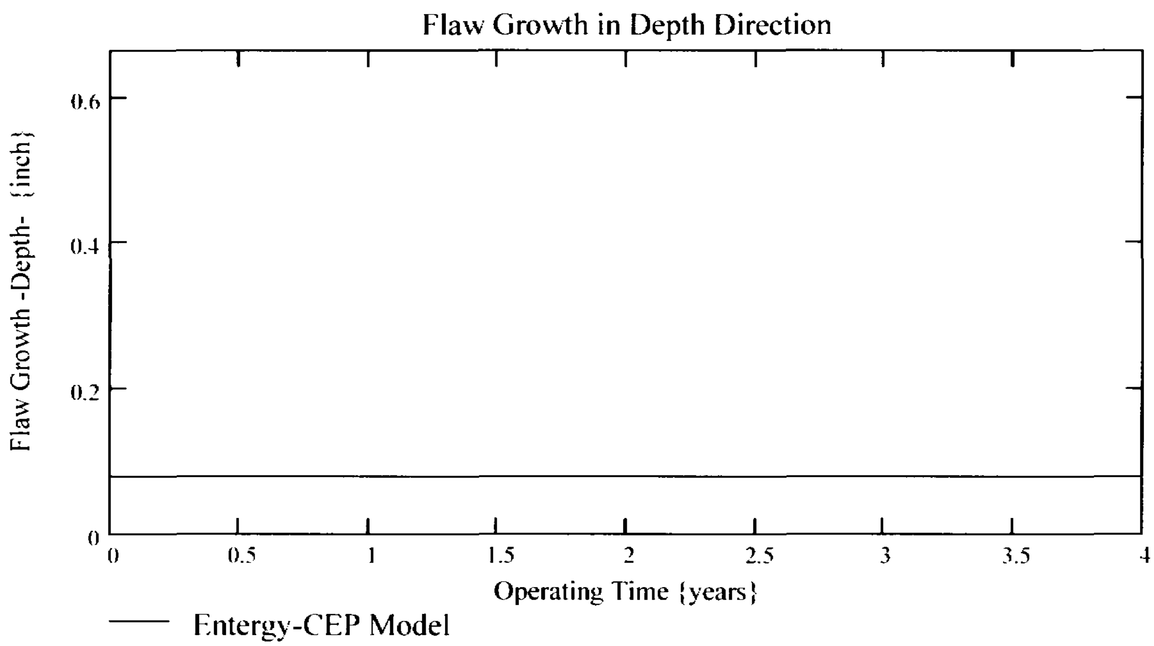
$U_{Tip} := FL_{Cntr} + c_0$

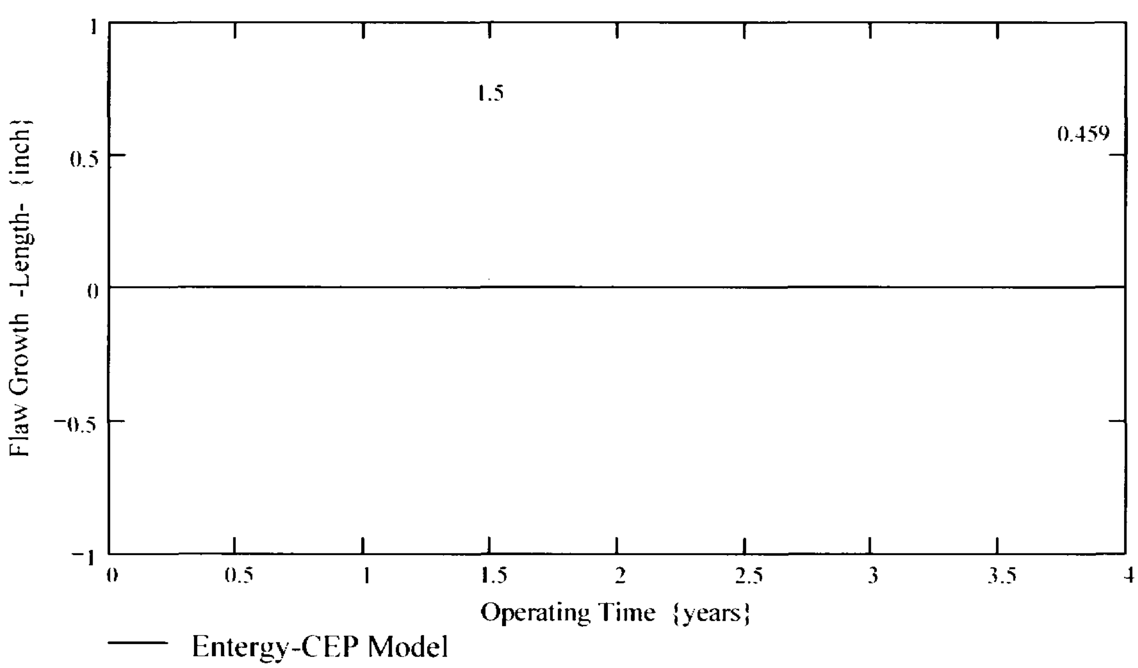
$Inc_{Strs.avg} := \dfrac{UL_{Strs.Dist} - U_{Tip}}{20}$

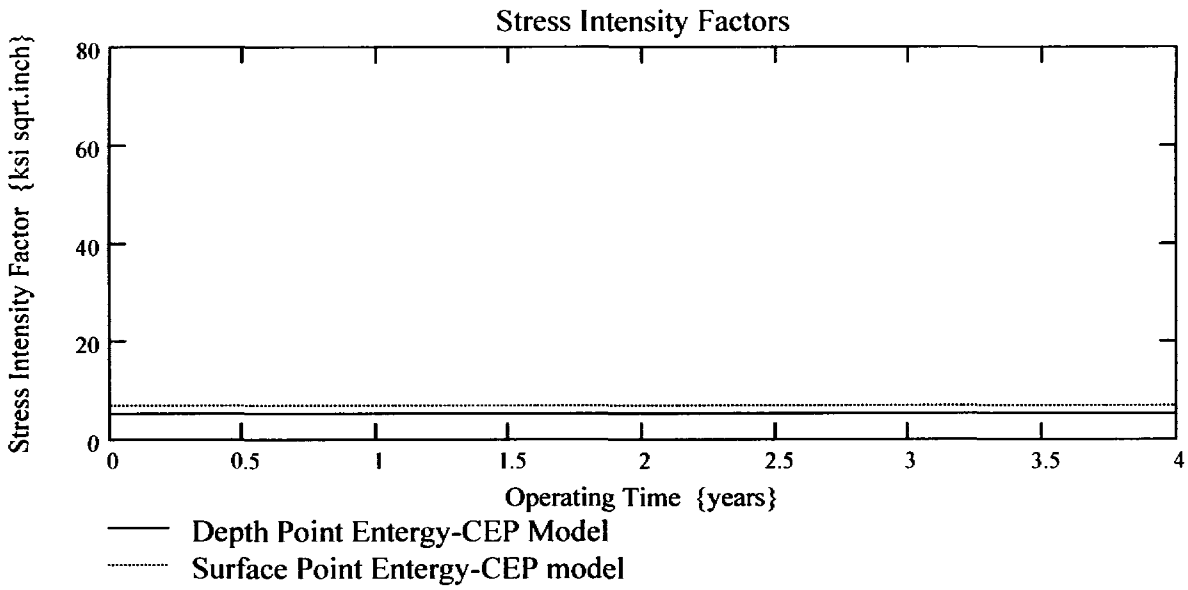
No User Input is required beyond this Point

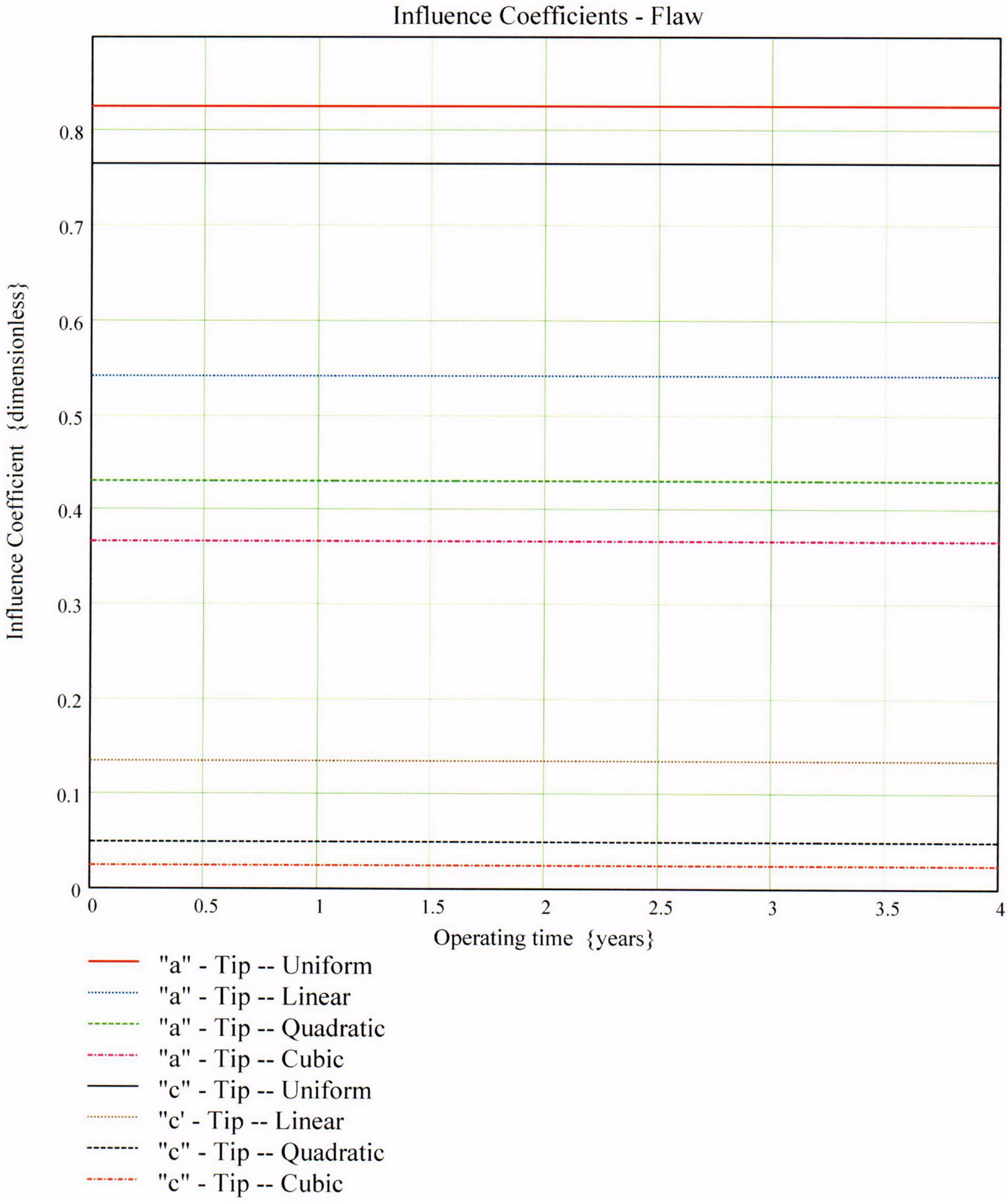
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.459$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

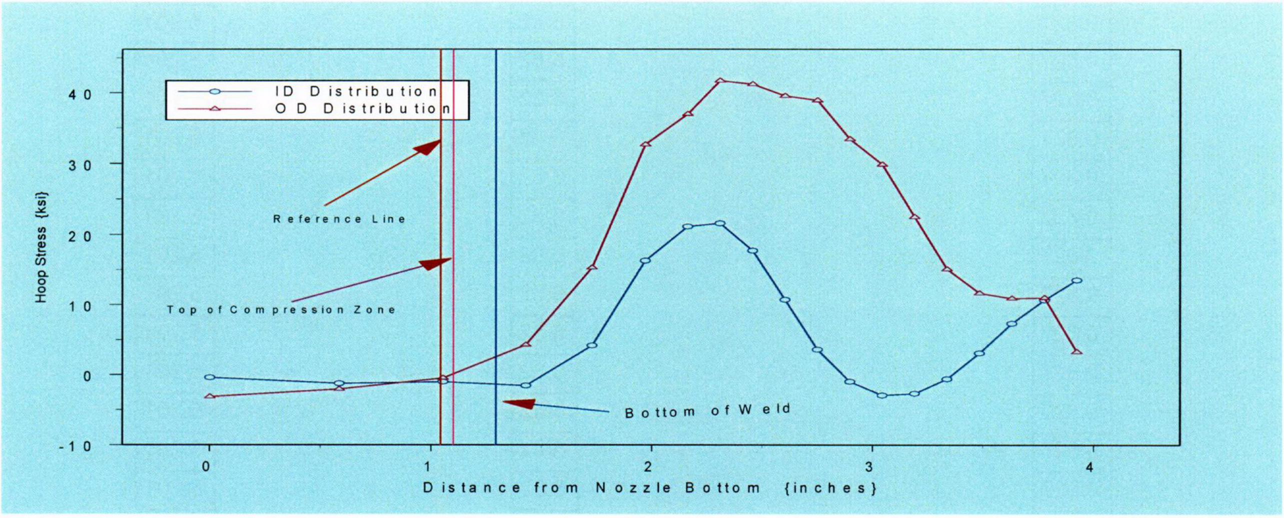
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

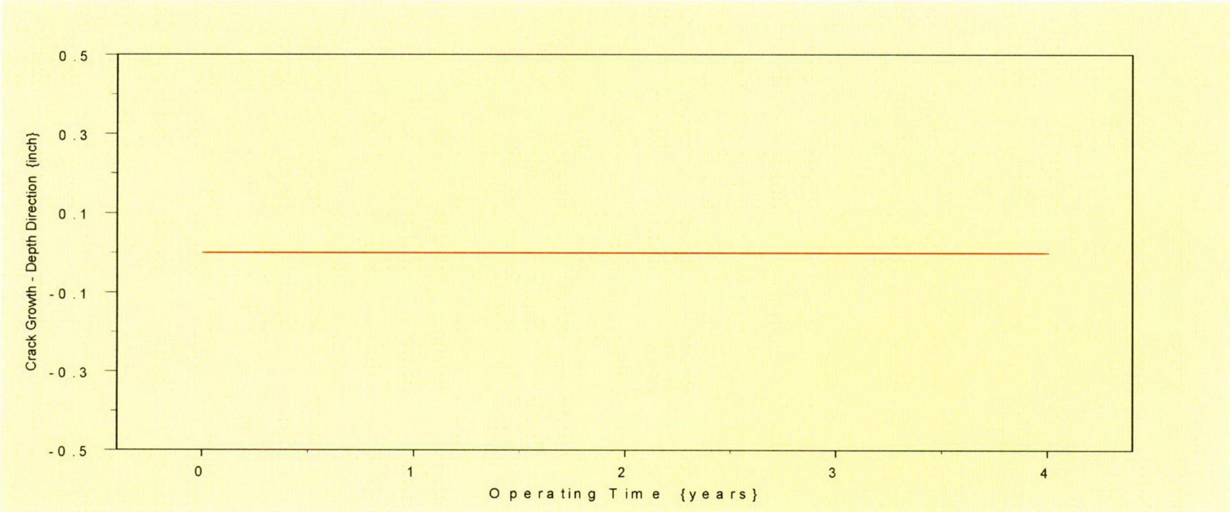
$CGR_{sambi_{(k,6)}} =$

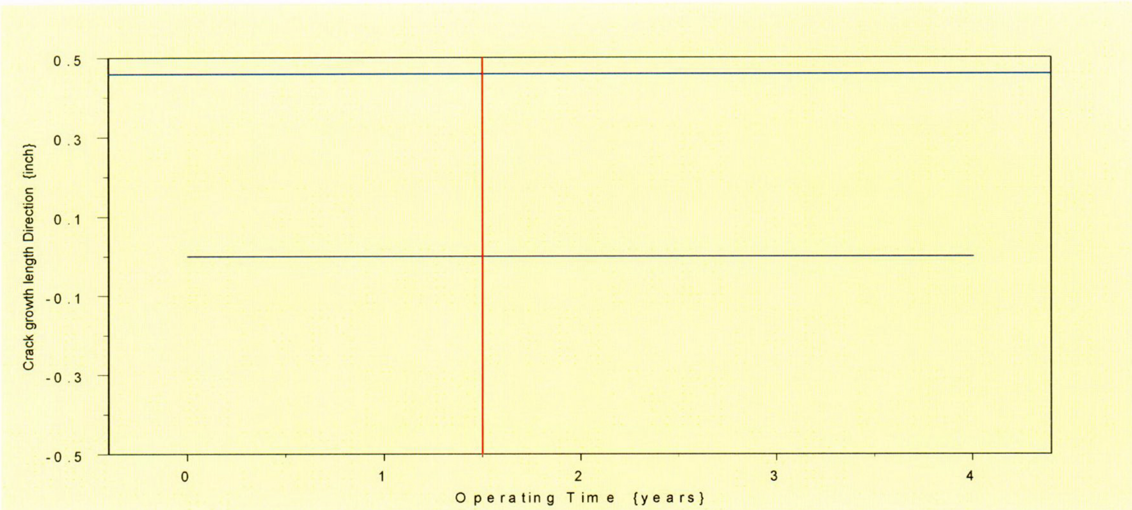
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82
6.82

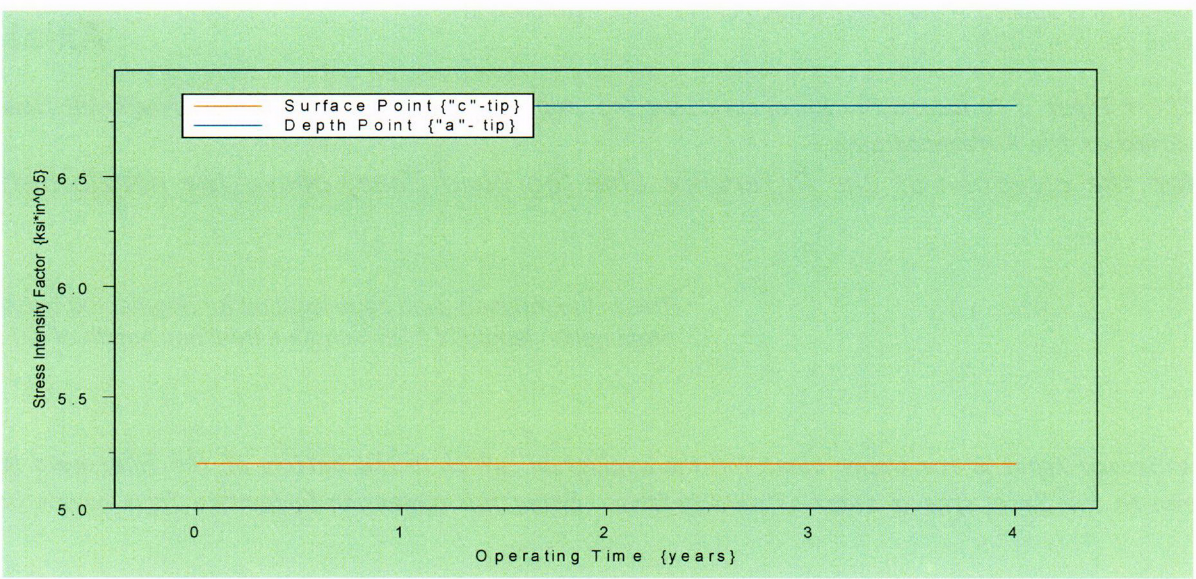
$CGR_{sambi_{(k,5)}} =$

5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201
5.201


ID Distribution
OD Distribution
Reference Line
Top of Compression Zone
Bottom of Weld
Hoop Stress (ksi)
40
30
20
10
0
-10
0
1
2
3
4
Distance from Nozzle Bottom {inches}


Crack Growth - Depth Direction {inch}
0.5
0.3
0.1
-0.1
-0.3
-0.5
0
1
2
3
4
Operating Time {years}


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack growth length Direction {inch}
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
6.5
6.0
5.5
5.0
Stress Intensity Factor {ksi*in^0.5}
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49"Degree Nozzle, 22.5 degree from Downhill Azimuth, Augmented Analysis 1.3 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : _Used the Metric form of the equation from EPRI MRP 55-Rev. 1_.
The correction is applied in the determination of the crack extension to obtain the value in inch/hr.

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.3$

This is the reduced blind zone location for augmented analysis; allows a propagation length of 0.25 inch an a freespan length of 0.0.25

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 1.5504$

Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.25$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$v := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^{5}$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

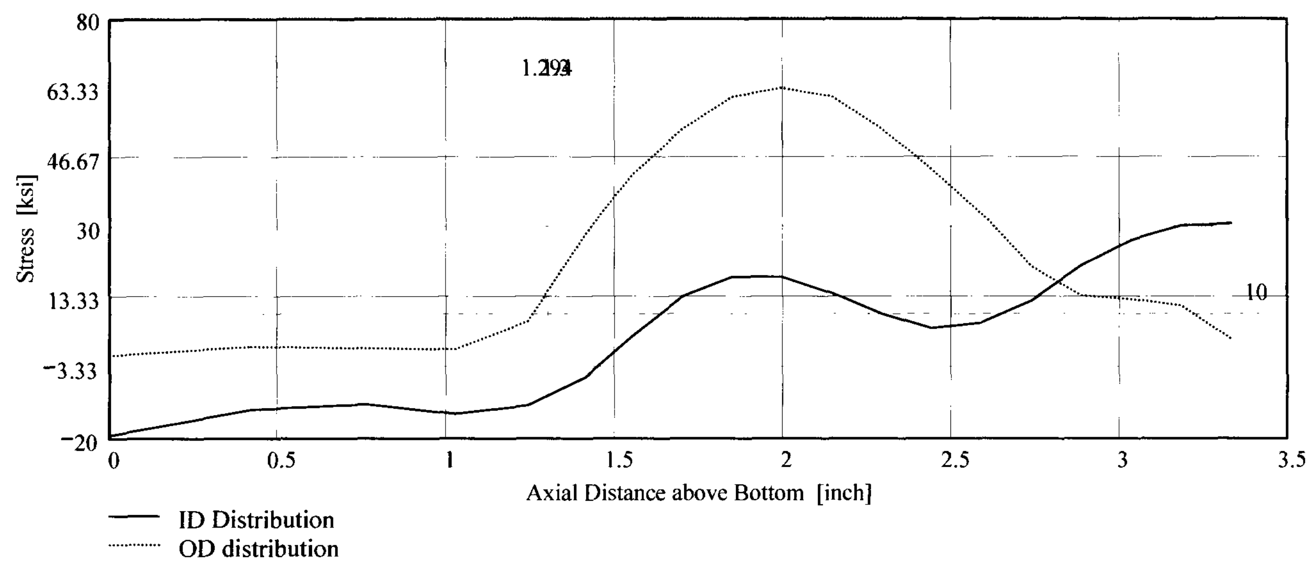
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-19.3	-12.52	-8.3	-4.31	-0.29
1	0.42	-13.15	-8.57	-4.68	-1.25	1.83
2	0.75	-11.83	-6.96	-2.68	0.03	1.46
3	1.02	-14.15	-8.31	-3.17	1.1	1.22
4	1.24	-12.13	-6.55	0	5.78	7.86
5	1.41	-5.38	-2.41	7.5	23.29	28.72
6	1.55	4.33	6.48	17.84	35.67	42.75
7	1.7	13.64	15.67	27.16	40.65	53.56
8	1.85	18.3	21.2	32.42	50.34	61.38
9	2	18.32	22.29	34.21	53.26	63.46
10	2.14	14.52	21.82	35.09	51.48	61.5
11	2.29	9.62	20.82	34.51	47.88	53.88

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $\quad AllID := Data_{All}^{\langle 1 \rangle}$ $\quad AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\mathrm{Data} := \begin{pmatrix} 0 & -19.301 & -12.523 & -8.304 & -4.314 & -0.289 \\ 0.419 & -13.153 & -8.572 & -4.68 & -1.255 & 1.834 \\ 0.755 & -11.834 & -6.958 & -2.685 & 0.028 & 1.463 \\ 1.024 & -14.146 & -8.315 & -3.168 & 1.103 & 1.221 \\ 1.239 & -12.132 & -6.552 & 3.002\times 10^{-3} & 5.78 & 7.858 \\ 1.412 & -5.38 & -2.413 & 7.498 & 23.29 & 28.718 \\ 1.55 & 4.331 & 6.478 & 17.842 & 35.67 & 42.747 \\ 1.699 & 13.644 & 15.667 & 27.164 & 40.65 & 53.563 \\ 1.847 & 18.304 & 21.201 & 32.424 & 50.345 & 61.379 \\ 1.996 & 18.316 & 22.292 & 34.208 & 53.258 & 63.464 \end{pmatrix}$$

$\mathrm{Axl} := \mathrm{Data}^{\langle 0 \rangle}$ $\mathrm{ID} := \mathrm{Data}^{\langle 1 \rangle}$ $\mathrm{OD} := \mathrm{Data}^{\langle 5 \rangle}$

$R_{ID} := \mathrm{regress}(\mathrm{Axl}, \mathrm{ID}, 3)$ $R_{OD} := \mathrm{regress}(\mathrm{Axl}, \mathrm{OD}, 3)$

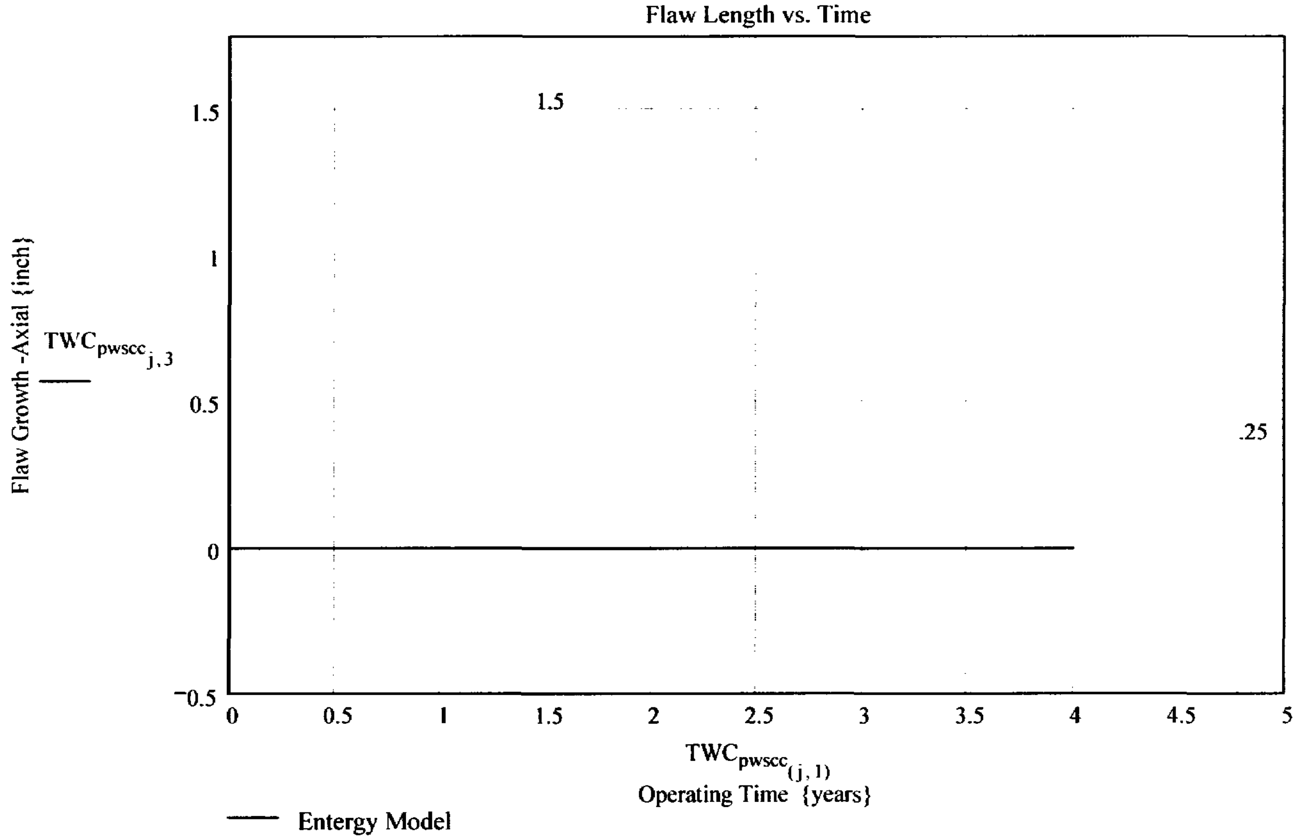
$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

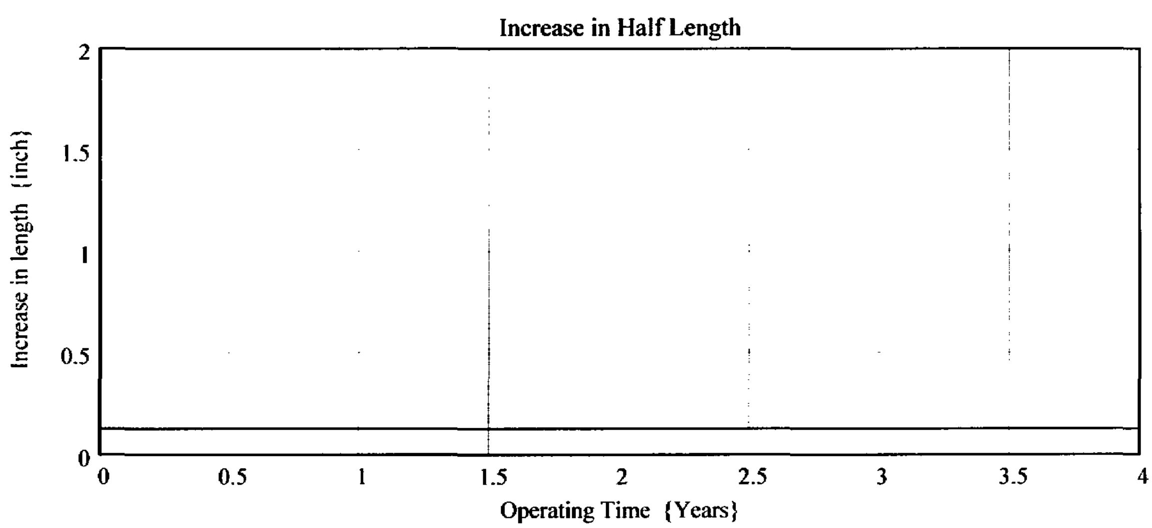
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

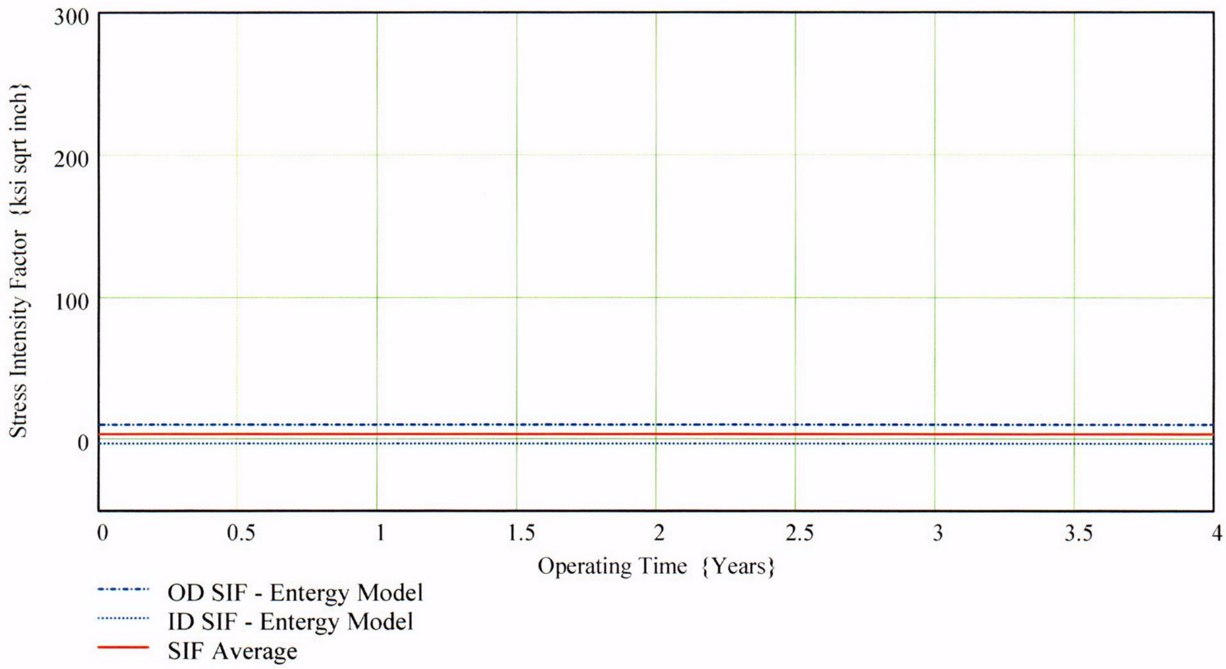
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

$Prop_{Length} = 0.25$







300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$

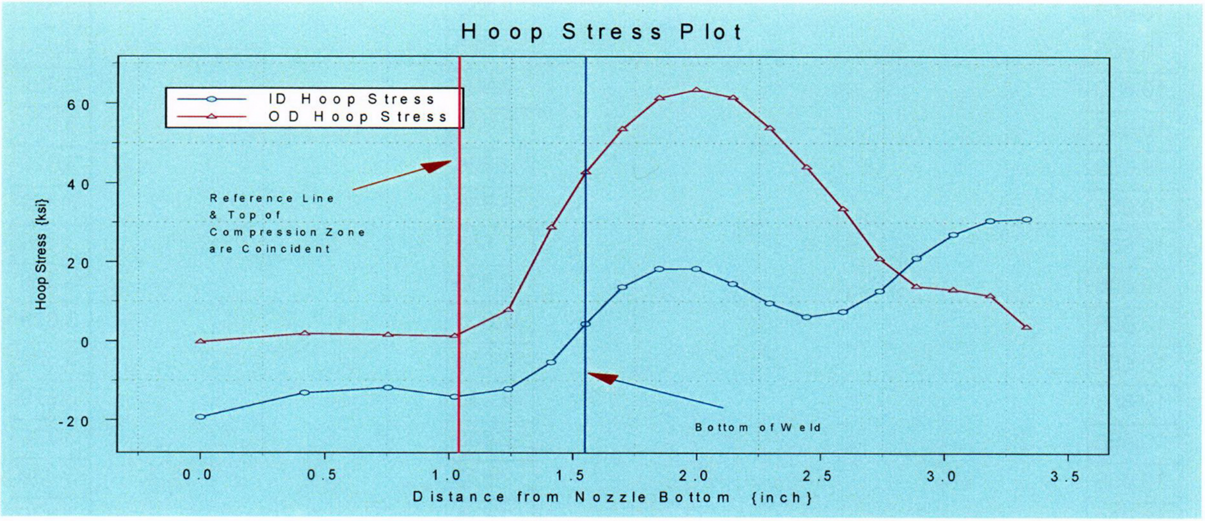
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656
10.656

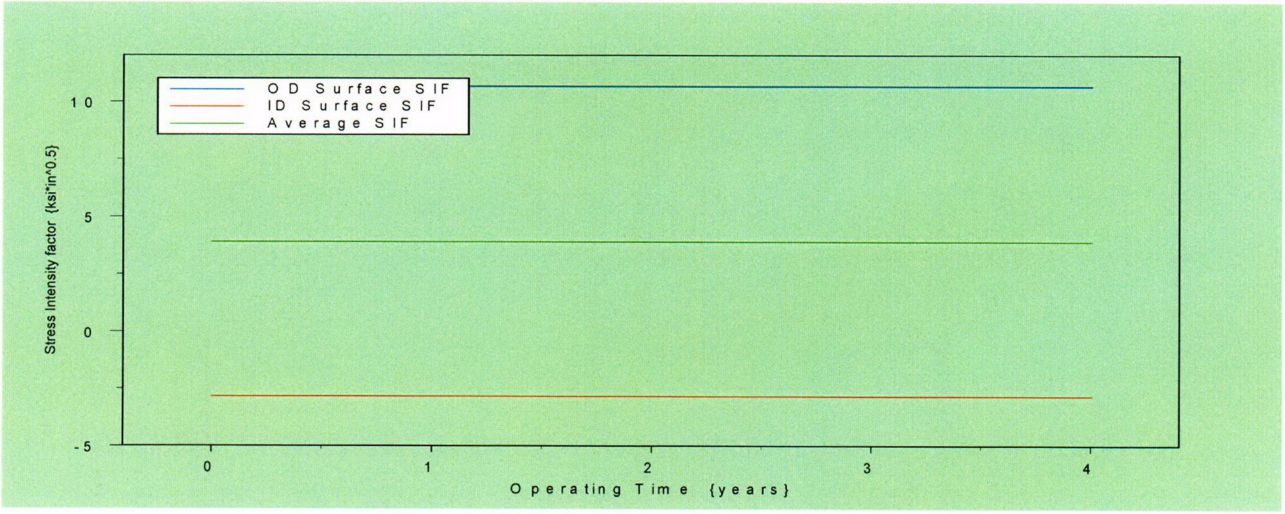
$TWC_{pwscc_{(j,7)}} =$

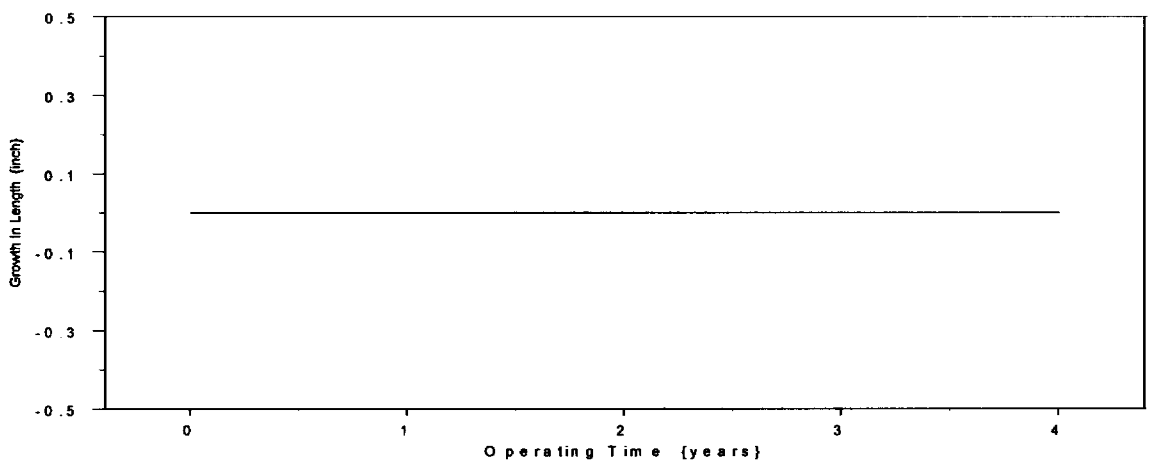
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835
-2.835

$TWC_{pwscc_{(j,8)}} =$

3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829
3.829


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Reference Line & Top of Compression Zone are Coincident
Bottom of Weld
Hoop Stress {ksi}
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
10
5
0
-5
0
1
2
3
4
Operating Time {years}



Developed by: _Verified by:_

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam Verified by: B. C. Gray

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thickwall Cylinder)

Refrences :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"49"Degree Nozzle, 45 degree from Downhill Azimuth, Augmented Analysis 1.544 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** .
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The throughwall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.544$ *This is the as-built blind zone location*

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 2.1632$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.25$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$v := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^5$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

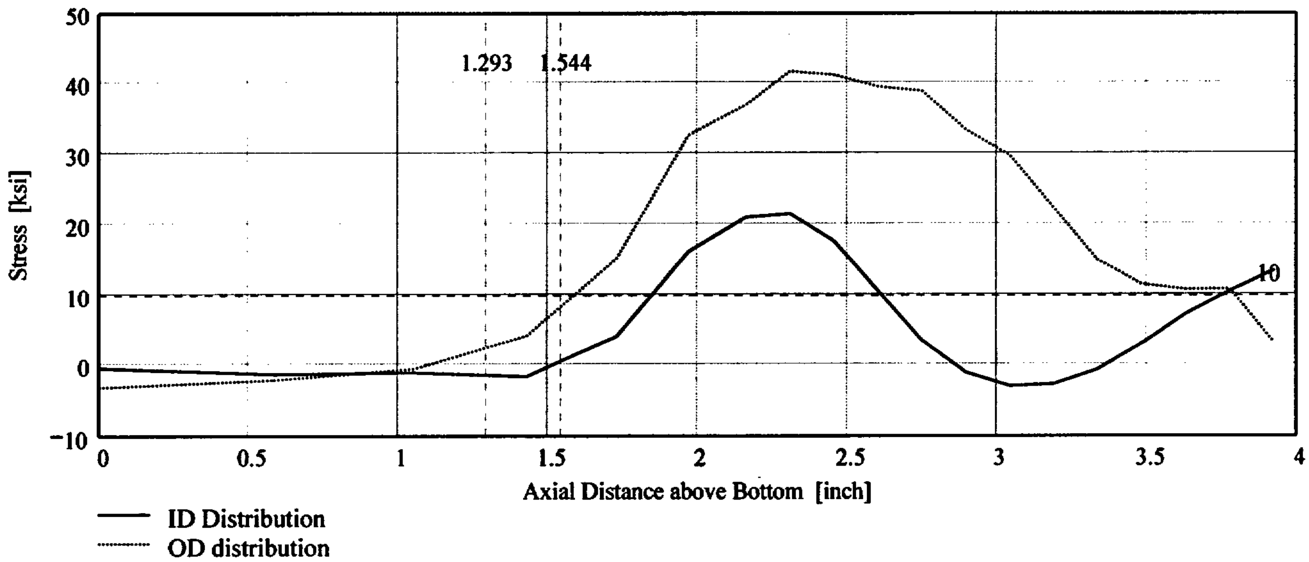
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-0.41	-1.36	-1.84	-2.37	-3.16
1	0.58	-1.26	-1.49	-1.71	-1.95	-2.07
2	1.05	-1.02	-0.22	0.35	0.52	-0.5
3	1.43	-1.56	0.62	2.58	4.9	4.26
4	1.73	4.17	4.31	8.86	13.38	15.25
5	1.97	16.26	12.54	16.93	28.26	32.67
6	2.16	21.13	17.13	20.09	34.28	36.98
7	2.31	21.59	19.09	21.93	34.05	41.72
8	2.46	17.7	17.82	22.18	34.47	41.21
9	2.6	10.69	14.25	21.11	33.32	39.55

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $\quad AllID := Data_{All}^{\langle 1 \rangle}$ $\quad AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled Data$_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\mathrm{Data} := \begin{pmatrix} 0 & -0.414 & -1.359 & -1.842 & -2.369 & -3.157 \\ 0.585 & -1.256 & -1.488 & -1.714 & -1.95 & -2.073 \\ 1.053 & -1.023 & -0.223 & 0.347 & 0.516 & -0.495 \\ 1.429 & -1.559 & 0.622 & 2.583 & 4.895 & 4.258 \\ 1.729 & 4.165 & 4.315 & 8.86 & 13.38 & 15.252 \\ 1.97 & 16.258 & 12.541 & 16.926 & 28.26 & 32.667 \\ 2.163 & 21.131 & 17.131 & 20.087 & 34.279 & 36.98 \\ 2.31 & 21.593 & 19.093 & 21.933 & 34.049 & 41.718 \\ 2.457 & 17.702 & 17.82 & 22.18 & 34.468 & 41.213 \end{pmatrix}$$

$\mathrm{Axl} := \mathrm{Data}^{\langle 0 \rangle}$ $\quad \mathrm{ID} := \mathrm{Data}^{\langle 1 \rangle}$ $\quad \mathrm{OD} := \mathrm{Data}^{\langle 5 \rangle}$

$R_{ID} := \mathrm{regress}(\mathrm{Axl}, \mathrm{ID}, 3)$ $\quad R_{OD} := \mathrm{regress}(\mathrm{Axl}, \mathrm{OD}, 3)$

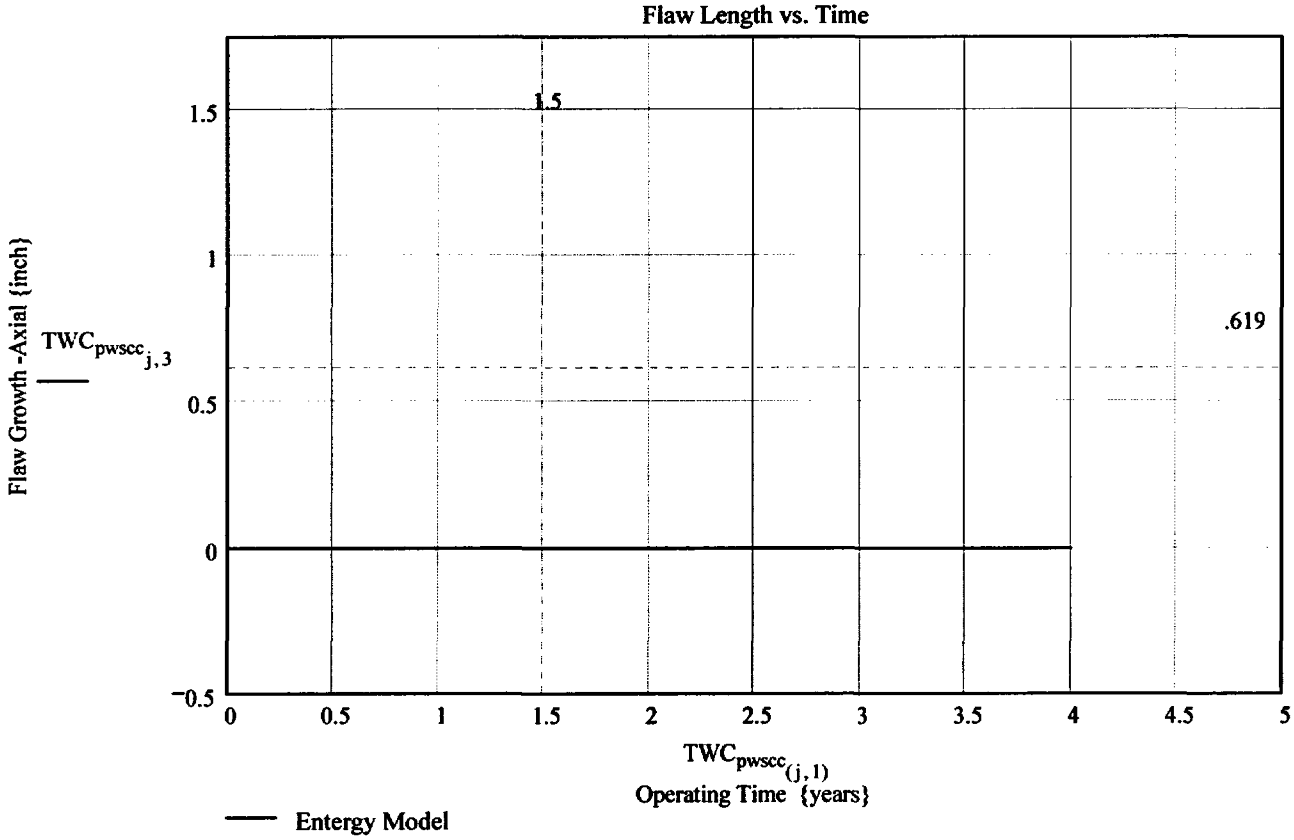
$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

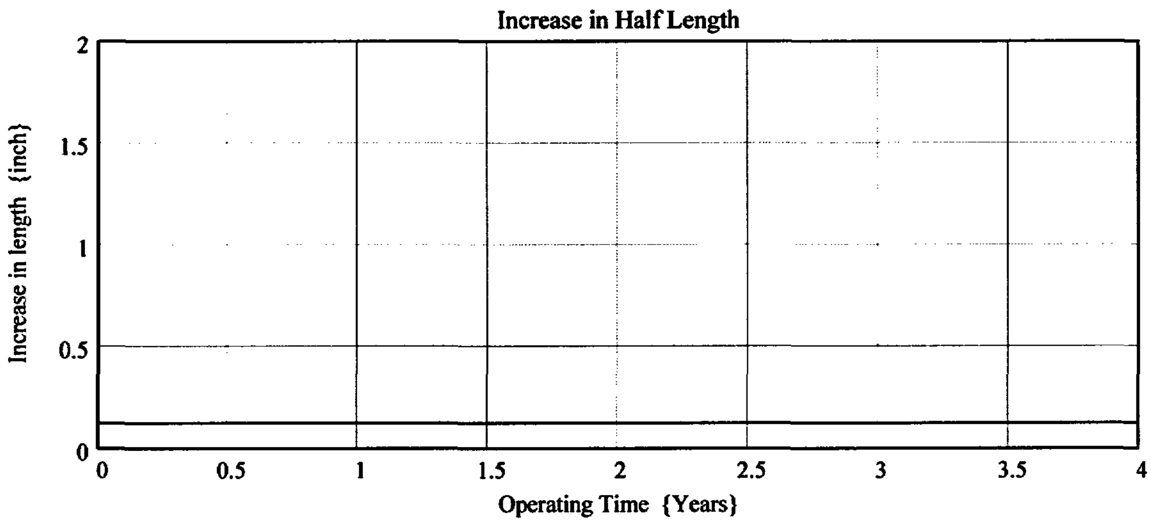
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

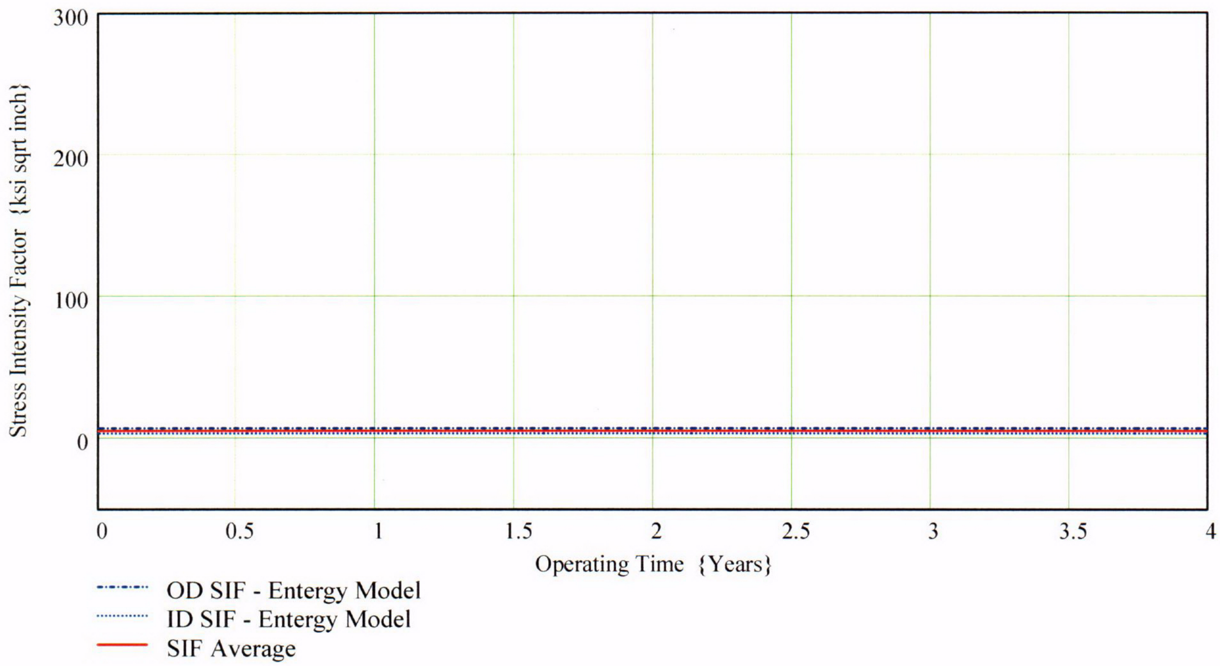
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

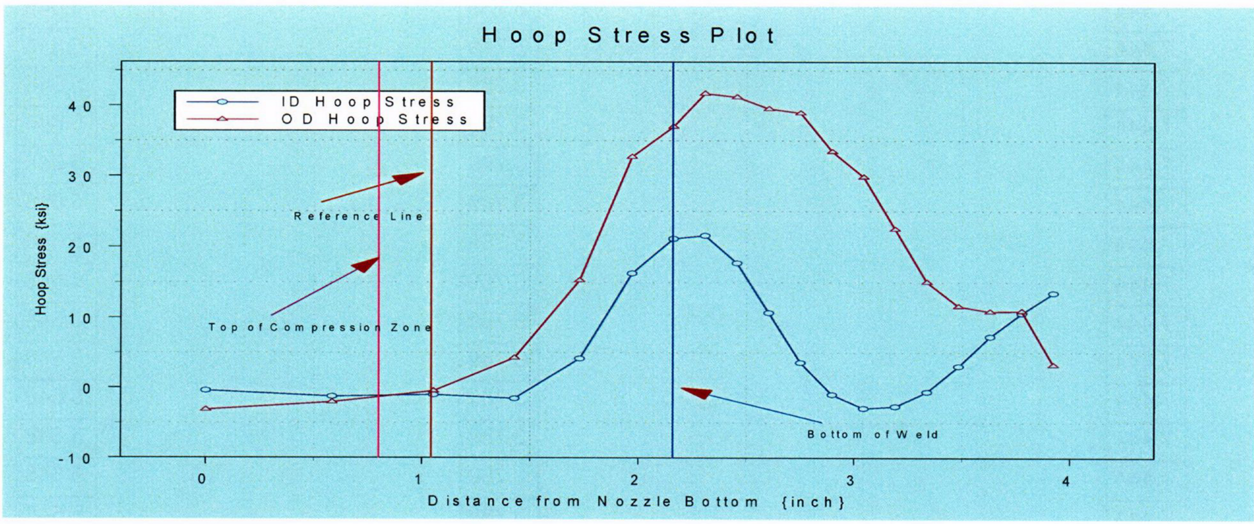
$Prop_{Length} = 0.619$

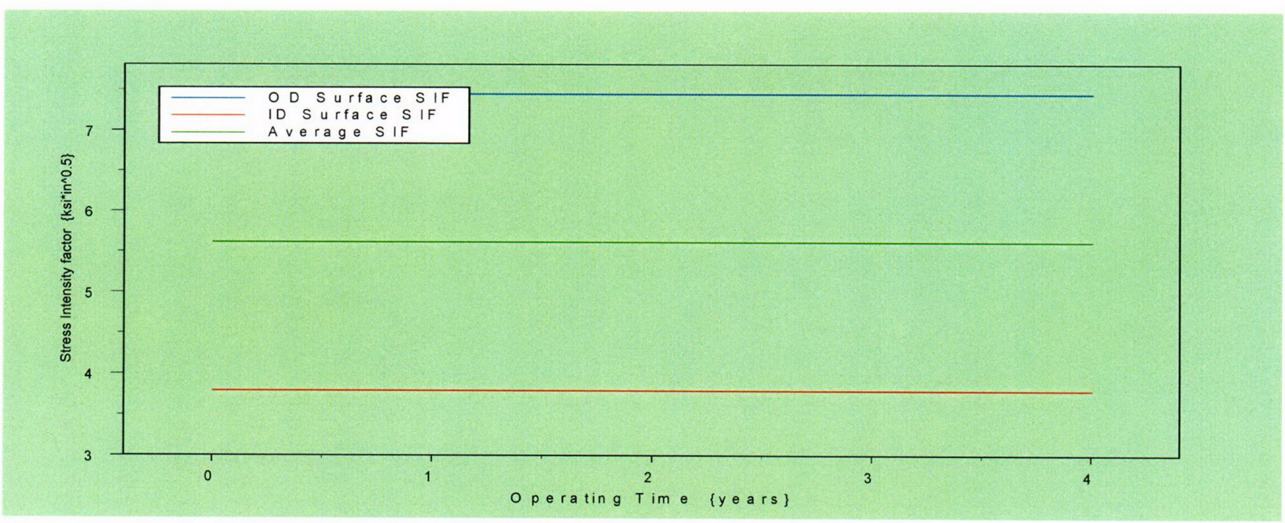


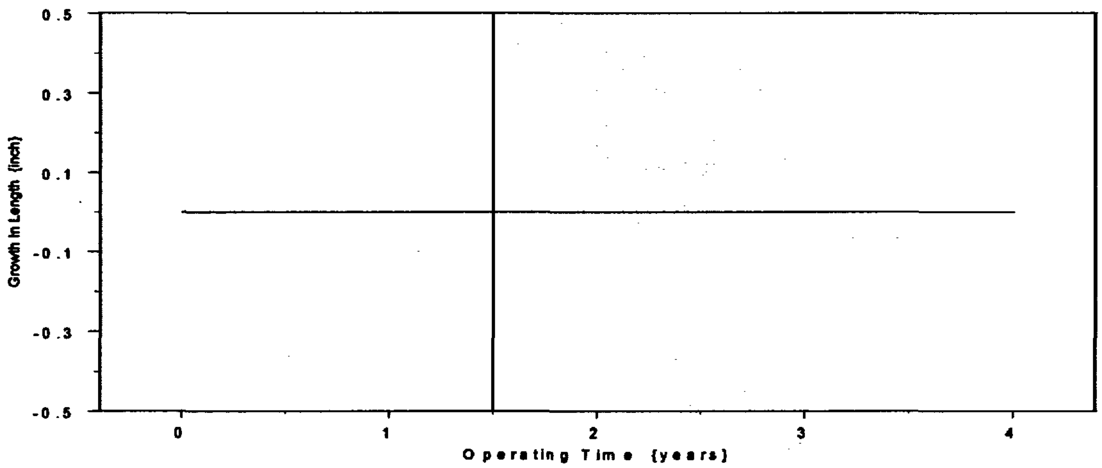



Stress Intensity Factor {ksi sqrt inch}
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$	$TWC_{pwscc_{(j,7)}} =$	$TWC_{pwscc_{(j,8)}} =$
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648
7.444	3.789	5.648


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Reference Line
Top of Compression Zone
Bottom of Weld
Hoop Stress {ksi}
Distance from Nozzle Bottom {inch}
40
30
20
10
0
-10
0
1
2
3
4


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
Operating Time {years}
7
6
5
4
3
0
1
2
3
4


0.5
0.3
0.1
-0.1
-0.3
-0.5
Growth in Length (inch)
0
1
2
3
4
Operating Time (years)

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc
Developedby: J. S. Brihmadesam **Verified by: B. C. Gray**

Refrences :

1) "Stress Intensity factors for Part-through Surface cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"0" Degree Nozzle, All Azimuth, Augmented Analysis 1.25" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

OD Surface Flaw

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessar to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represnets the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.25$ *This is the reduced blind zone; providing a propagation length of 0.386 inch; freespan length is 0.546 inch*

To place the flaw with repsect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$$Val := 2$$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.796$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.661 \cdot 0.12$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$R_o := \frac{od}{2} \qquad R_{id} := \frac{id}{2} \qquad t := R_o - R_{id} \qquad R_m := R_{id} + \frac{t}{2} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$CF_{inhr} := 1.417 \cdot 10^5 \qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right| \qquad c_0 := \frac{L}{2} \qquad R_t := \frac{R_m}{t}$$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$$C_0 := C_{01}$$ 75 th percentile MRP-55 Revision 1

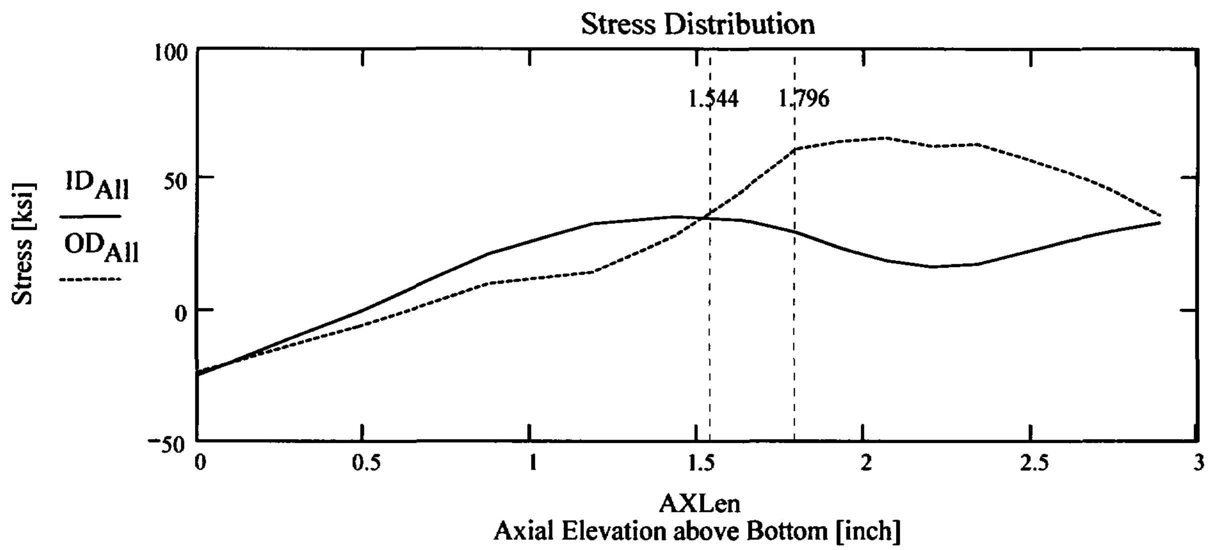
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum to maximum recorded on data sheet(inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-25.09	-27.55	-27.79	-25.62	-23.76
1	0.49	-0.56	-0.54	-2.11	-4.85	-6.16
2	0.87	21.52	18.64	17.12	14.84	10.09
3	1.19	32.75	28.49	24.14	19.64	14.45
4	1.44	35.67	29.6	26.17	25.59	28.42
5	1.64	34.24	29.57	28.29	35.41	45.38
6	1.8	29.45	29.81	31.39	43.34	61.71
7	1.93	23.67	26.5	33.26	47.61	64.65
8	2.07	18.93	24.56	33.97	49.07	65.88
9	2.2	16.54	22.85	34.79	49.52	62.8

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled Data$_{All}$ that represents the

region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$\text{Data} := \begin{pmatrix} 0 & -25.088 & -27.546 & -27.787 & -25.624 & -23.763 \\ 0.485 & -0.563 & -0.539 & -2.111 & -4.851 & -6.157 \\ 0.874 & 21.515 & 18.635 & 17.122 & 14.843 & 10.089 \\ 1.186 & 32.751 & 28.494 & 24.136 & 19.645 & 14.45 \\ 1.436 & 35.667 & 29.598 & 26.166 & 25.589 & 28.417 \\ 1.635 & 34.244 & 29.574 & 28.286 & 35.408 & 45.379 \\ 1.796 & 29.45 & 29.814 & 31.385 & 43.337 & 61.713 \\ 1.932 & 23.674 & 26.502 & 33.261 & 47.609 & 64.65 \\ 2.068 & 18.928 & 24.564 & 33.968 & 49.071 & 65.876 \end{pmatrix}$$

$\text{Axl} := \text{Data}^{\langle 0\rangle}$ $\text{MD} := \text{Data}^{\langle 3\rangle}$ $\text{ID} := \text{Data}^{\langle 1\rangle}$ $\text{TQ} := \text{Data}^{\langle 4\rangle}$ $\text{QT} := \text{Data}^{\langle 2\rangle}$ $\text{OD} := \text{Data}^{\langle 5\rangle}$

$R_{ID} := \text{regress}(\text{Axl}, \text{ID}, 3)$ $R_{QT} := \text{regress}(\text{Axl}, \text{QT}, 3)$

$R_{OD} := \text{regress}(\text{Axl}, \text{OD}, 3)$

$R_{MD} := \text{regress}(\text{Axl}, \text{MD}, 3)$ $R_{TQ} := \text{regress}(\text{Axl}, \text{TQ}, 3)$

$$FL_{Cntr} := \begin{array}{|l} Ref_{Point} - c_0 \ \text{ if } Val = 1 \\ Ref_{Point} \ \text{ if } Val = 2 \\ Ref_{Point} + c_0 \ \text{ otherwise} \end{array}$$

Flaw center Location Location above Nozzle Bottom

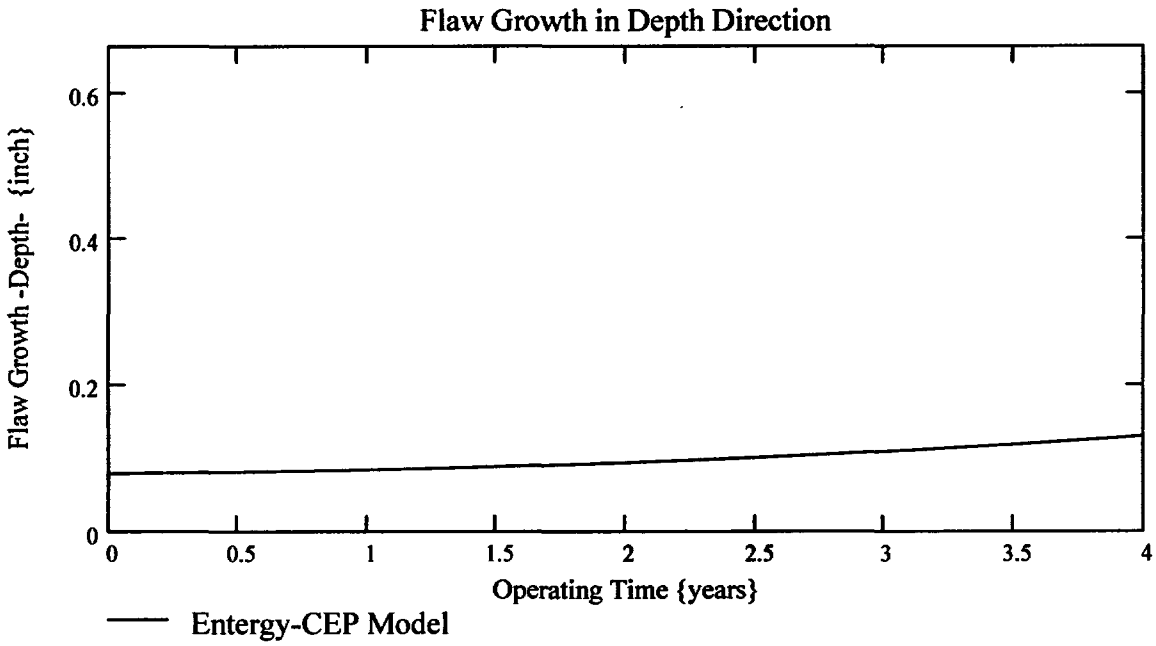
$U_{Tip} := FL_{Cntr} + c_0$

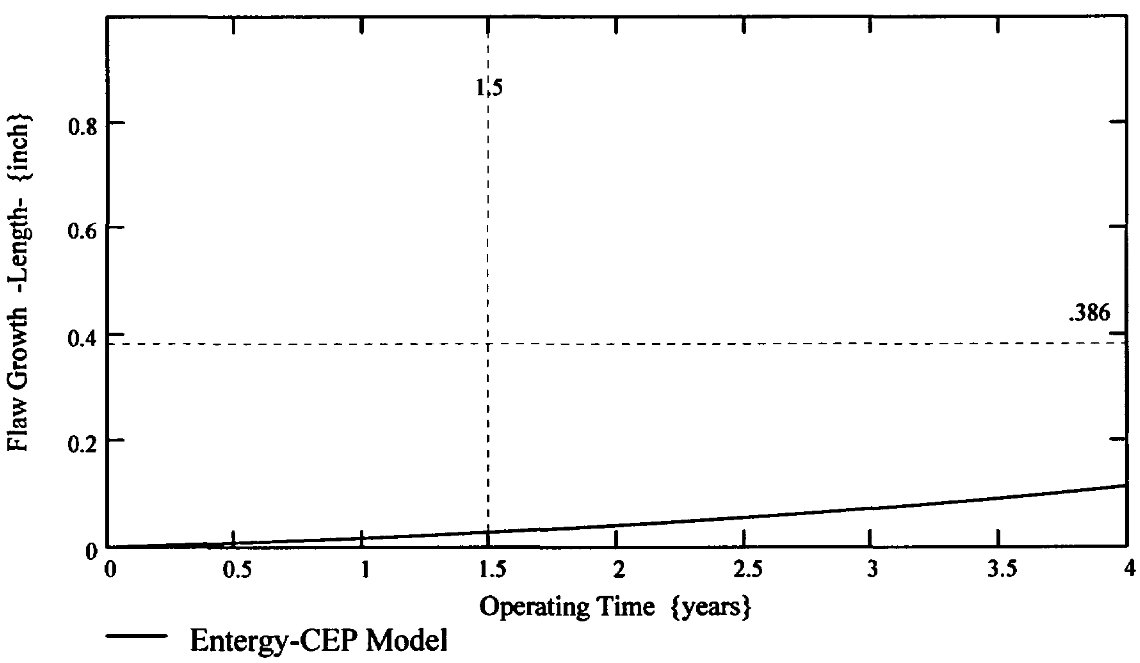
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

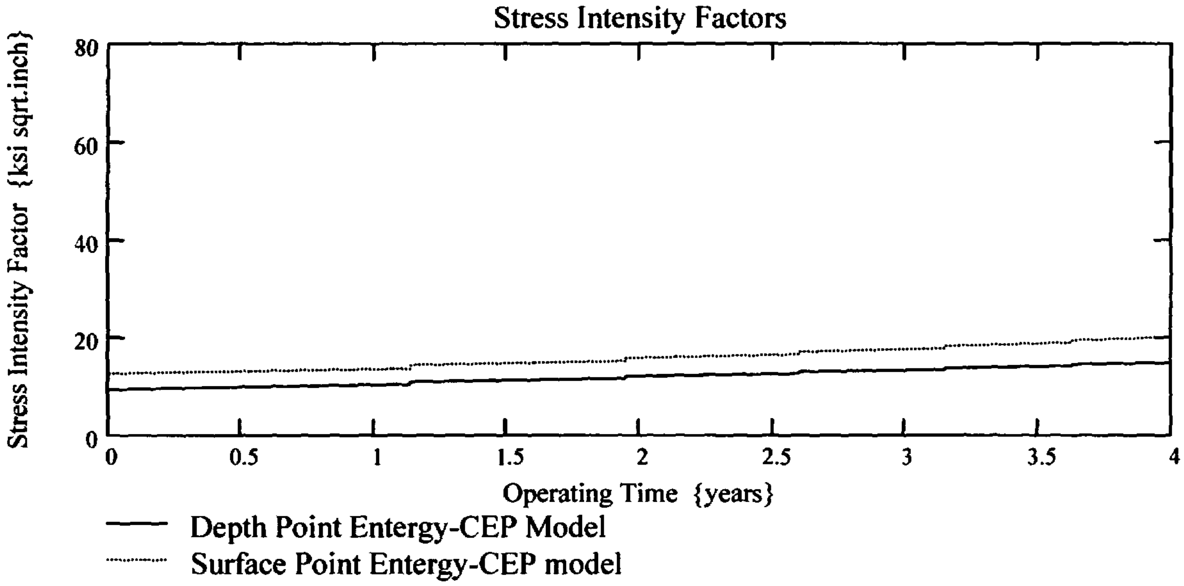
No User Input is required beyond this Point

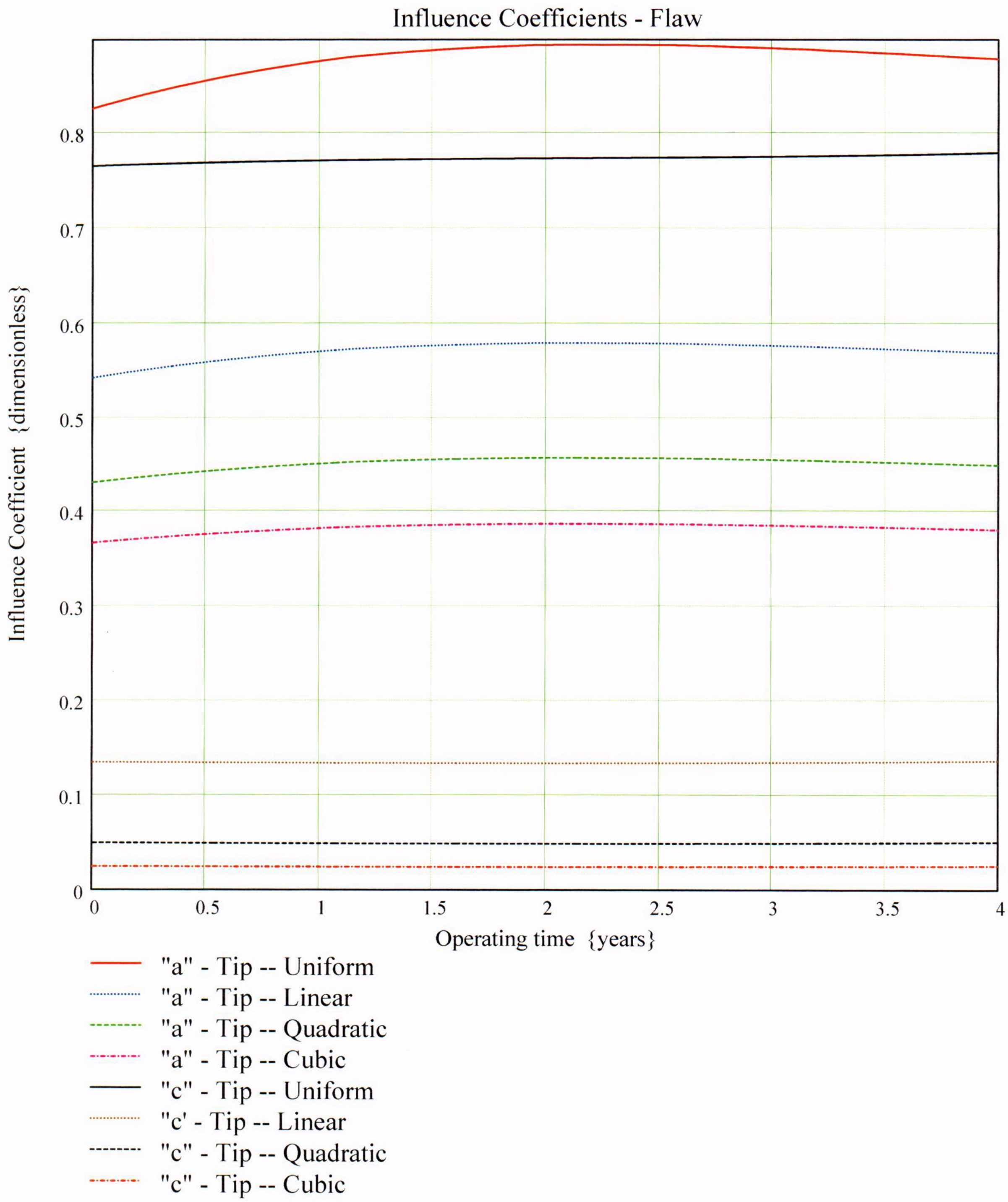
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.386$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

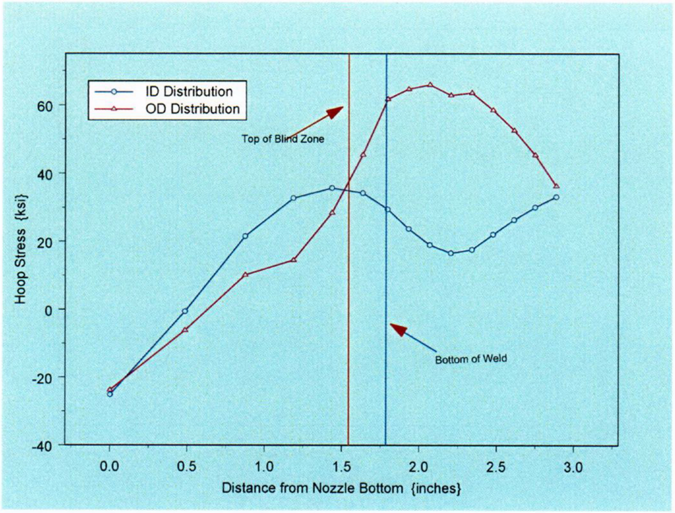
0.827
0.827
0.827
0.827
0.827
0.828
0.828
0.828
0.828
0.828
0.828
0.829
0.829
0.829
0.829
0.829

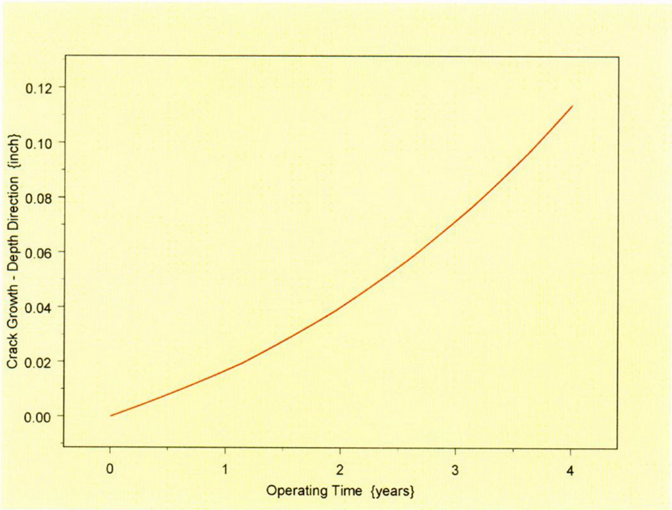
$CGR_{sambi_{(k,6)}} =$

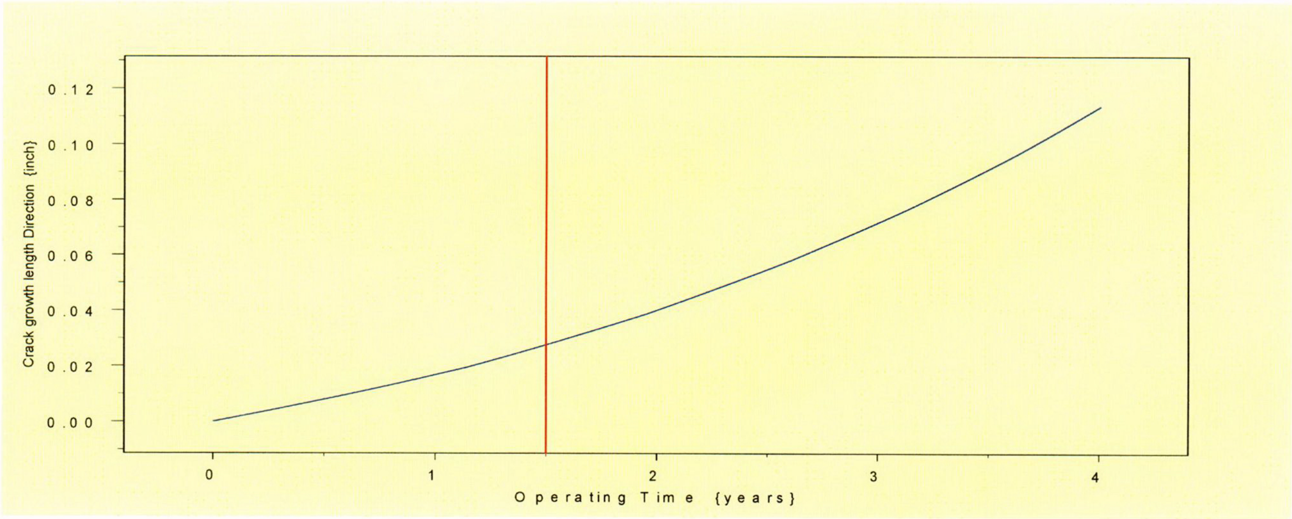
11.641
12.616
12.618
12.621
12.623
12.625
12.628
12.63
12.633
12.635
12.637
12.64
12.642
12.645
12.647
12.649

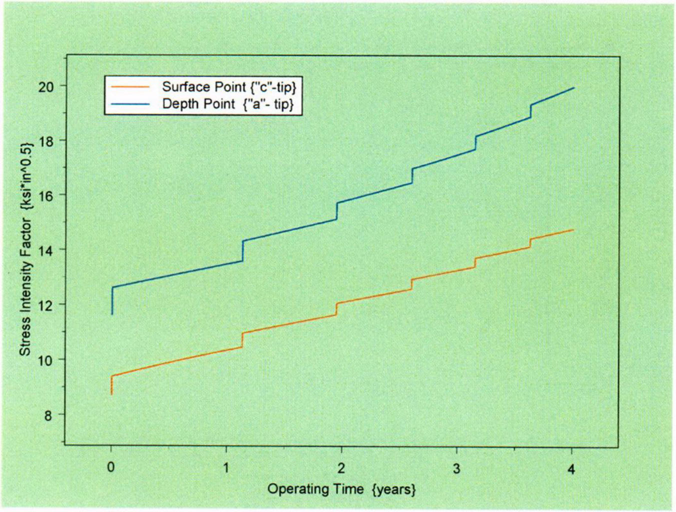
$CGR_{sambi_{(k,5)}} =$

8.723
9.389
9.392
9.395
9.398
9.401
9.403
9.406
9.409
9.412
9.415
9.418
9.421
9.424
9.427
9.43


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom {inches}


Crack Growth - Depth Direction {inch}
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Operating Time {years}


Crack growth length Direction {inch}
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
20
18
16
14
12
10
8
0
1
2
3
4
Operating Time {years}